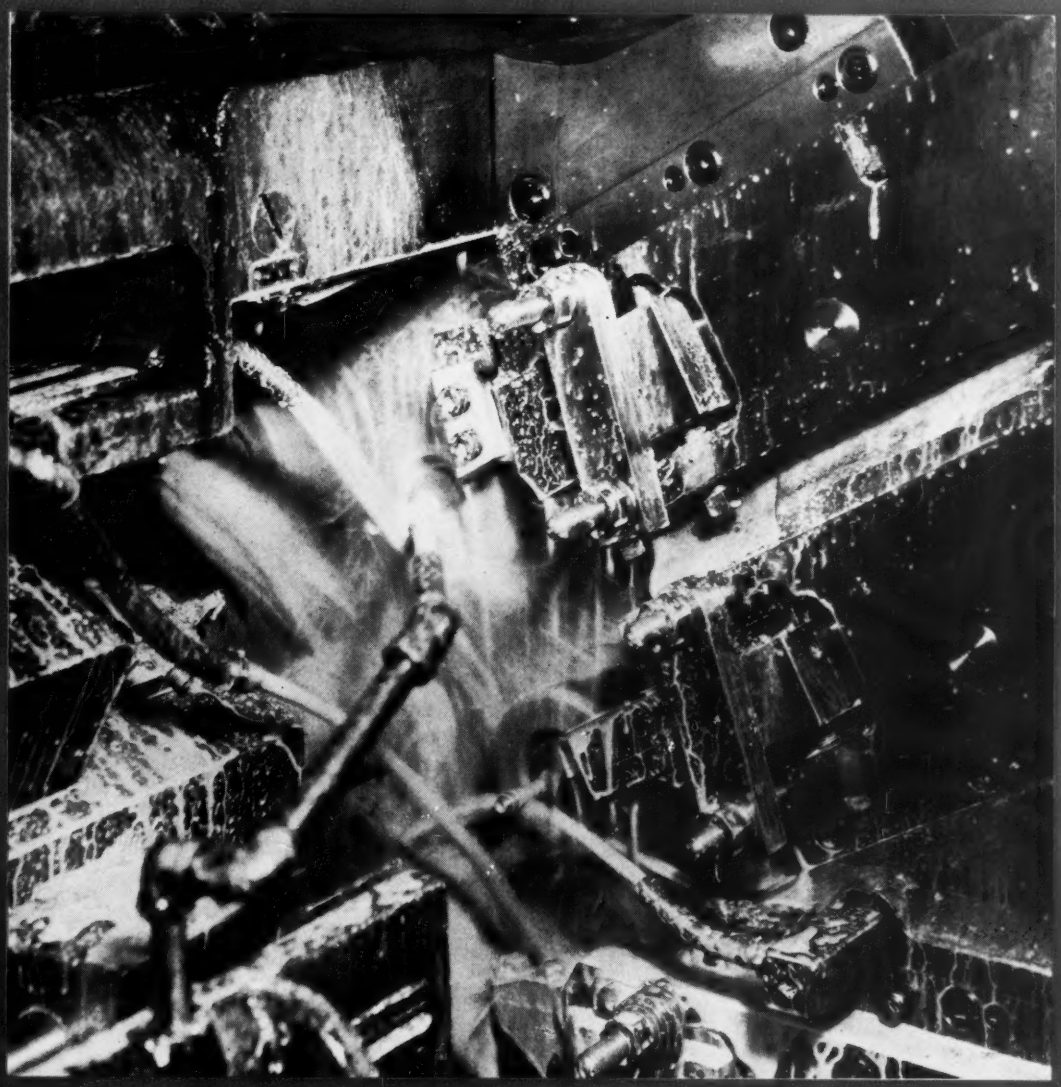
Vol. 13, No. 11 November, 1957

LUBRICATION ENGINEERING

RESEARCH APPLICATION EDUCATION MAINTENANCE



JOURNAL OF THE AMERICAN SOCIETY OF LUBRICATION ENGINEERS

Farval serves 1133 mill and crane bearings in Atlantic Steel's new bar and rod mill

FARVAL—
Studies in Centralized Lubrication
No. 205

KEYS TO ADEQUATE LUBRICATION—

Inset above shows Farval automatic pumping station No. 3, serving 240 points on 15 horizontal mills, edging mill, furnace switch and pullout. Above you see *Farvalized* overhead crane and runout tables in the Atlantic Steel Co. mill room.

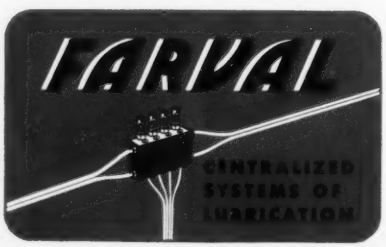
●Last word for modern machines and manufacturing practice, this Atlanta steel company also employs the most modern method of lubrication—Farval Centralized Lubrication. Twenty-four Farval systems keep mills and cranes running smoothly, serving a total of 1133 bearings.

You'll generally find Farval in evidence wherever steel is made or worked. Literally thousands of systems, automatic and manually operated, protect millions of bearings in the metals industries—some of them still efficiently on the job after 25 to 30 years of service.

Farval is the original Dualine system of centralized lubrication that delivers measured amounts of oil or grease under pressure to every bearing as often as desired. No bearing is ever missed.

Write for newly revised Bulletin 26-S, which tells the whole Farval story. The Farval Corporation, 3267 E. 80th St., Cleveland 4, Ohio.

Affiliate of The Cleveland Worm & Gear Company, Industrial Worm Gearing.
In Canada: Peacock Brothers Limited.



LUBRICATION ENGINEERING

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Abstracted by Engineering Index

LUBRICATION ENGINEERING is published monthly by the American Society of Lubrication Engineers, 84 E. Randolph St., Chicago 1, Illinois. Current volume single copies 75c. Copies of issues from previous volumes $1.00, if available; Copies to Foreign addresses add 50c per copy. Annual Subscription $6.00 in the USA and Canada, $7.00 to all other countries.

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Carefully metered quantities of oil are applied to each lubrication point, providing more thorough lubrication with a few ounces of oil per day than other methods using several gallons.

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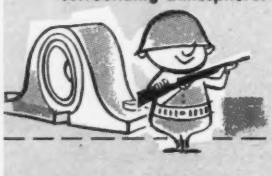
A slight pressure is maintained within the bearing with air continuously escaping and preventing entrance of contaminants from surrounding atmosphere.



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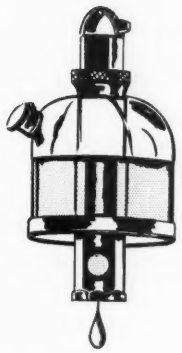


Highlights of Articles Scheduled for Coming Issues!

Service Experience with a New Multipurpose Industrial Grease

Conventional greases are petroleum products thickened with a metal soap of a fatty acid. Recently, a new synthetic gelling agent has permitted the development of a multipurpose grease for industrial applications that does not compromise various lubricant properties as do many special purpose greases. Tests indicate the product to be compatible with all known grease types, permitting the product's use in existing lubrication systems. The author describes a wide range of applications under various service conditions and unusual and severe service are cited.

A New Thickener for Multipurpose Lubricating Grease

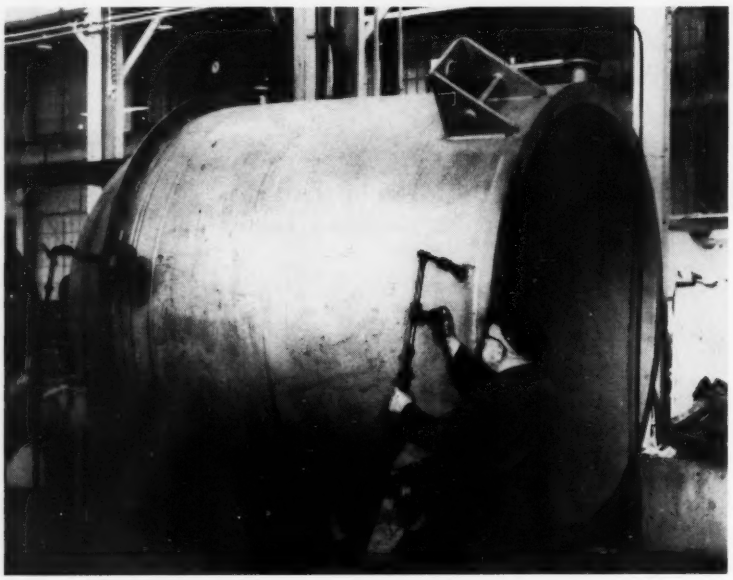
By reacting an isocyanate with an amine in a mineral oil suitable for use as a grease, a new multipurpose grease has been developed which has fibers resembling those of a lithium soap, and a low thickener content. The grease possesses high drop points, excellent resistance to oxidation, water resistance, working resistance, and leakage resistance. Field tests are described for the new product. A table included shows typical properties of a grease thickened with the new material.

Lubrication Standards for Industrial Equipment

Much of industry still regards lubrication as unimportant because, unlike an electrical failure, immediate machine stoppage doesn't follow a lubrication failure. Maintenance problems which have accompanied increased mechanization have been lessened by application of JIC electrical, hydraulic, and pneumatic standards. Lack of standards for lubrication has caused choice of lubricating devices and methods to be left to the machinery manufacturer. The standardization of lubrication for industrial equipment has proved profitable to one major company and its adoption is urged throughout industry.

LUBRICATION IN THE NEWS

Giant Stainless Grease Mixer Uses New Radial Design



PITTSBURGH, PA. — A newly designed giant grease mixer, one of the first to be made of stainless and stainless clad steel plates, is now in production for one of the leading petroleum companies.

Just under ten feet in height, the huge mixer when completed will hold 22,500 pounds of mixture per batch. Besides combining the various automotive and machine greases, the new equipment can be used in the manufacture of soap, oil, and other additives to soap stock or other like mixtures.

Stainless steel was specified because some of the additives to grease are corrosive while in the mixing process. The 1½-inch side plates of the mixer will be made of 10 per cent clad stainless, and the 5/8-inch hemispherically shaped bottom plates will have 20 per cent stainless steel clad material over carbon steel. The agitator and paddles are of solid stainless steel. Type 304 stainless is being used because this type is noted for its corrosion resistant qualities.

The new design calls for a sweep frame agitator with center paddles being independently driven by constant torque driven motors located on the top of the kettle. This mixer is so designed to receive a bottom radial propeller driven motor which will also give constant torque.

Sugar, Hydrocarbons Combined In New Process

NEW YORK — A unique method of combining sugar with petroleum compounds to produce materials of wide industrial potentialities as detergents, petroleum additives, pharmaceuticals, plasticizers, resins and germicides was described at the American Chemical Society's 132nd national meeting here.

The process affords a convenient and economical way to make a whole range of promising compounds from two of the most abundant and inexpensive classes of chemicals—carbohydrates, related to sugar, and hydrocarbons, derivatives of petroleum — according to its inventor, Dr. Carl B. Linn of the Universal Oil Products Company, Des Plaines, Ill. Some of the products are completely new, and others were formerly inaccessible from an economic point of view, the research chemist said. In the laboratory experiments reported by Dr. Linn, ordinary table sugar, starch, cellulose and glucose (a simple sugar made from starch) were "hooked up" chemically with toluene, ethylbenzene, phenol and other petroleum derivatives through the use of hydrogen fluoride, "a work-horse catalyst of petroleum industries."

The new process was described as follows: The carbohydrate and the hydrocarbon are sealed in a stainless steel vessel which is cooled with dry ice because of the large amount of heat generated by the reaction. Hydrogen fluoride (HF) is piped in and the mixture stirred until the action is complete. The excess HF is separated out and the product purified.

Drafting Standards Approval Seen Step To Uniformity

NEW YORK—Approval of four sections of the American Drafting Standards Manual Y14 by the ASA and publication by ASME was heralded as a move toward "a common written language for engineers in all trades and professions". Thirteen more sections are being developed to complete the manual, jointly sponsored by ASME and the American Society for Engineering Education.

The first four sections of the manual approved as American Standards are: Size and Format; Line Conventions, Sectioning and Lettering; Pictorial Drawings; and Dimensioning and Notes.

New Over-Running Clutch Assembly Cuts Lube Need

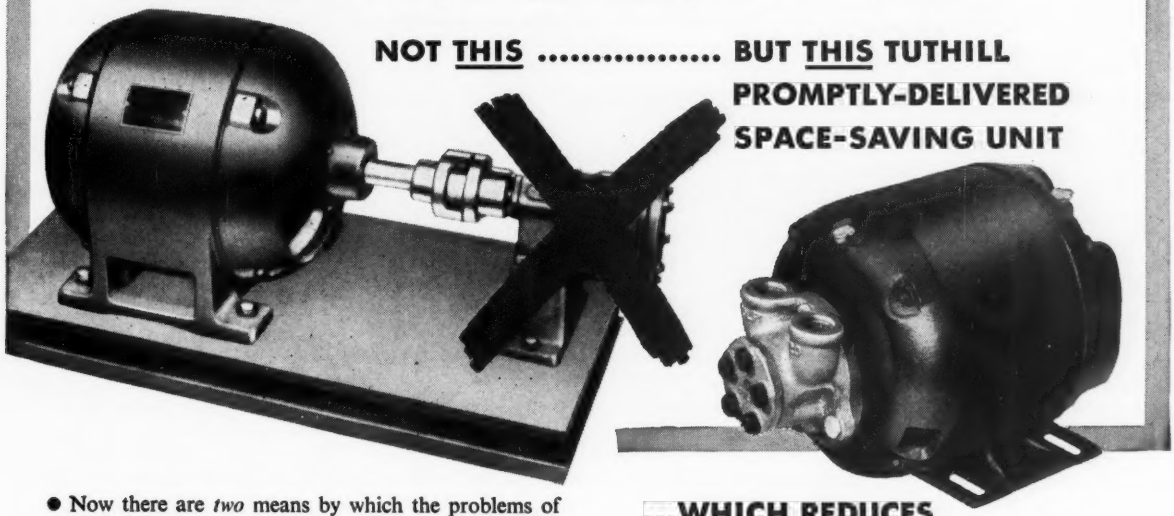
ELMIRA, N. Y. — The development of a new centrifugally operated over-running clutch assembly designed for automotive, commercial and industrial applications has been announced by the Eclipse Machine division of Bendix Aviation Corporation.

The unique clutch, which officials said will cover a wide range of power performance, features a "minimum amount of over-running friction," due to the centrifugal action, they said. It can be used to transmit power from a starter to a motor or engine, and also can be applied to dual engine-driven generators, water pumps, reel unwinder drives in steel mills, and paper slitting machines, as well as multiple-speed drives.

Bendix cited the following advantages of the unit, which can be built for any torque capacity: lower cost due to improved design; substantially smaller space requirements; minimum lubricating problems with many designs requiring no lubrication; less over-running torque, and less limitations to over-run speed.

NOW AVAILABLE!

New TUTHILL Positive Displacement Pump-and-Driving-Motor Units Require Less Space ...Have No Couplings, Adapters or Base



● Now there are *two* means by which the problems of space, weight, time and cost can be solved in the application of hydraulic, oil burning and lubricating pumps and motors to industrial equipment.

First, the use of compact, custom-built TUTHILL "POWERMITE" pump-and-driving-motor units for original equipment manufacturers having QUANTITY requirements.

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Both provide—with no coupling, adapter, or base:

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A typical standard TUTHILL pump-and-driving-motor unit is shown above. Note that *the pump is mounted on the motor*...eliminating the need for coupling, adapter and base...and time normally required for their assembly. In comparison with a regular assembly, the new driving unit saves a minimum of 6 inches in space and weighs several pounds less. The TUTHILL rotary positive displacement pumps used in these driving units range in flow capacity from 20-300 GPH and in pressures up to 1500 PSI. The combinations include ¼ HP motors and larger.

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LUBRICATION IN THE NEWS

New Carbide Technique Protects Graphite Parts

"A recently developed, novel technique for placing a hard, refractory, smooth and wear-resistant coating on machined graphite parts, should be of great interest to many segments of American industry." So says Morris A. Steinberg, head of metallurgy at Horizons Inc., process and material research organization.

According to Steinberg, "the new technique, which provides a carbide coating may not only better the performance of graphite parts now in use in industry, but also create new areas of application."

A broad range of possible uses for the coated parts is seen from nuclear reactors to die casting machine inserts. The coating is integrally bonded to the graphite, and its smoothness is a function of the smoothness with which the base graphite can be prepared. Coatings are complete, even in undercuts, holes, drilled areas, milled sections and the like. Thicknesses can be varied between 40 microns and 250 microns. Above this limit, the material tends to exfoliate.

In the specified thickness, the coating shows excellent heat shock resistance and integrity under cyclic conditions. Melting point is 2000° C. or higher, with a hardness of 2000 Vickers minimum. In reducing and vacuum atmospheres, the coating is chemcially stable.

Steinberg notes several possible applications for the new coating are indicated. "In liquid reactor cores, such as the type now being constructed, uranium bismuth or thorium bismuth slurries are utilized in liquid form under a substantial head of pressure. An unprotected graphite core can absorb a substantial amount of the liquid, and impede the continuous operation of the reactor. Carbide coated graphite may reduce or completely eliminate this potential absorption. Similar coating applications on graphite may prove useful in the process of gasification of coal, which requires a nuclear reaction and the use of graphite in the form of spheres.

"Another possible application is the coating of graphite fixtures which are used to hold honeycomb parts now coming into wide use in the construction of supersonic aircraft and missiles. These 'honeycombs', sealed as a support between two layers of metal, must be soldered or brazed to the external layers in large furnaces at temperatures of around 1800° F. To hold these parts in position in the furnace, graphite fixtures are used. During the process, the fixtures suffer severe corrosion and erosion at a rapid pace due to wear and atmospheric influences, even though the process is carried out in a hydrogen atmosphere. Carbide coatings may greatly lengthen the service life of these fixtures, while retaining all the other characteristics which make graphite useful in this application."

Another area of potential study is the replacement of silicon carbide inserts in the die casting of aluminum and copper alloys with coated graphite inserts. Silicon carbide, used in this application to maintain temperature control, is almost impossible to machine. Graphite, on the other hand, is an easily machined material.

Industry Groups Sponsor Skilled Machinist Program

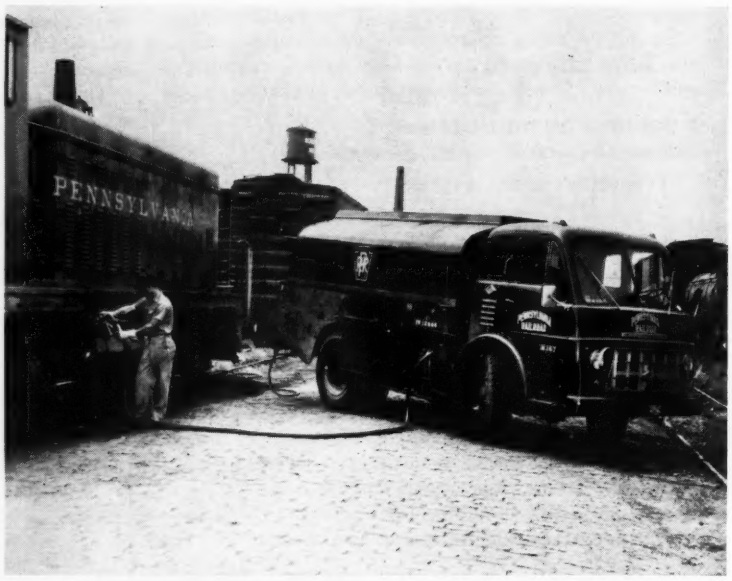
Los Angeles—An industry-taught grass roots training program aimed at upgrading skilled and semi-skilled workers has been launched by screw machine products firms here, in conjunction with various local educational organizations. Opening of the first session this month marks the culmination of a plan begun last February, when "teacher training" courses were initiated for experienced screw machine foremen and operators. A shortage of skilled labor in the area was said to have motivated the program.

With the problem of qualified teachers solved, more than 100 students attending the first of four semesters will receive instruction in cutting feeds and speeds, coolants and lubricants, the theory of cutting metal, cutting tool angles, and the proper use of micrometers and other measuring tools and gauges. Following semesters will deal with blueprint reading, mechanical drawing, shop mathematics, and tool and cam design. Courses are being held at the Los Angeles Trade Technical Junior College.

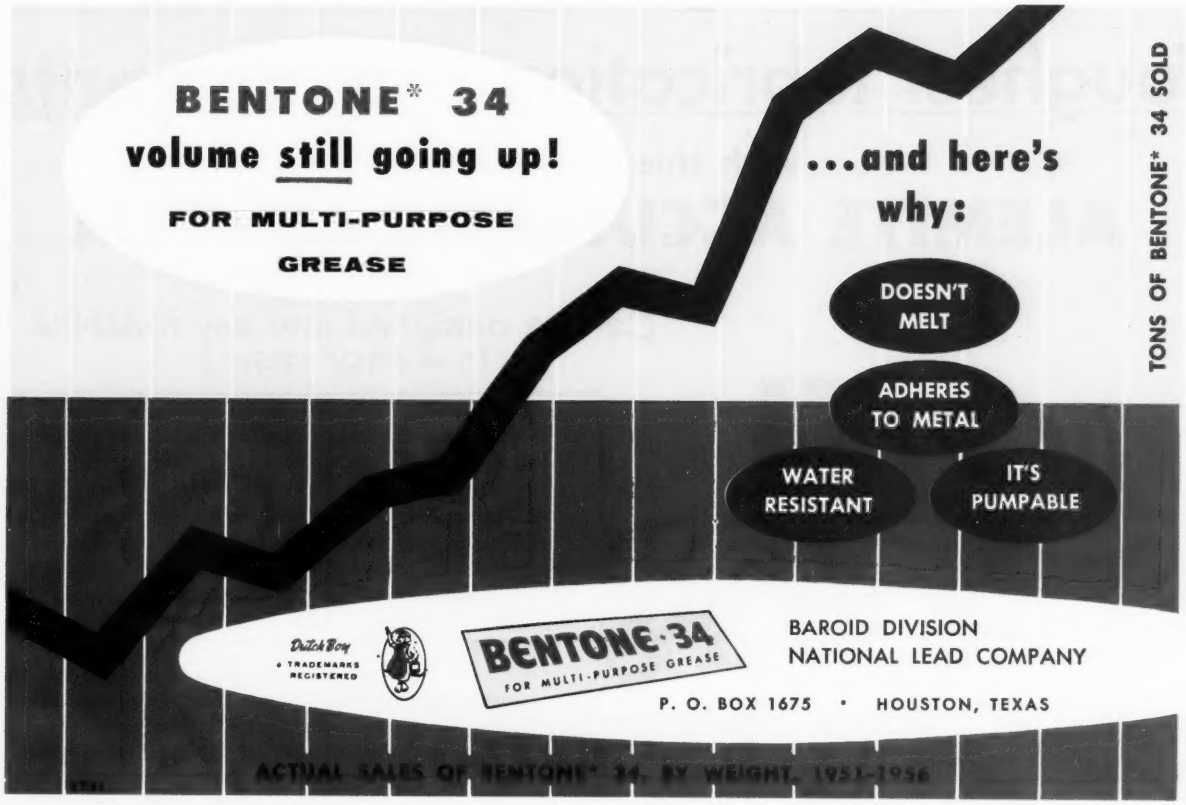
Denser Polyethylenes Show Wide Structure Possibilities

Improved properties of high density polyethylenes with higher tensile strengths, temperature resistances, and rigidity will have startling results from the standpoint of structural fabrication, predicts J. A. Neumann, president of American Agile Corp., polyethylene producers. The polyethylenes are a class of the newer materials whose relatively low coefficient of friction when not lubricated makes them suitable for bearing surfaces.

Writing in his company's external publication, Dr. Neumann states that "the tensile strength of the new polyethylenes can be as high as 600 psi, compared with a maximum of 2000 psi for low density polyethylenes produced by previous conventional methods.



New mobile lubricating and refueling unit, built by Farrell Mfg. Co., Joliet, Ill., can service diesel locomotives anywhere on railroad property, eliminating the need for large permanent installations in central yards. Unit holds lubricant and fuel for one or more locomotives, and also carries sand to fill traction hoppers.



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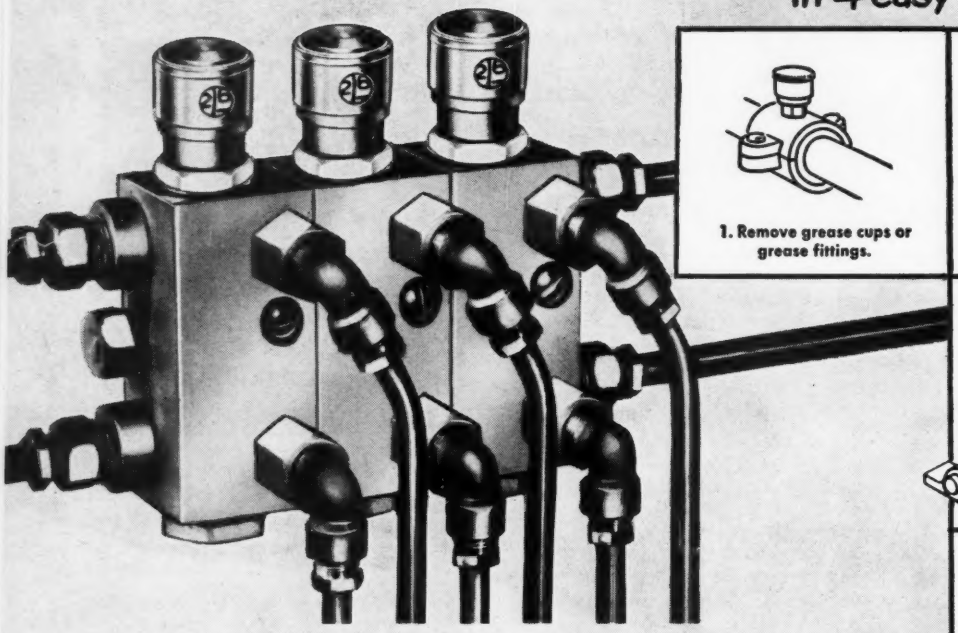
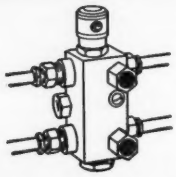
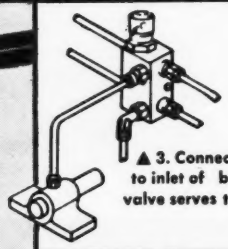


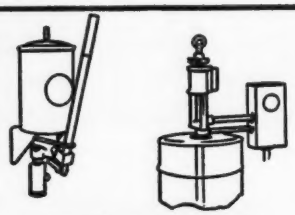
1. Remove grease cups or grease fittings.



2. Connect each valve in system to its two lubricant supply lines.



▲ 3. Connect valve outlets to inlet of bearings. (Each valve serves two bearings.)



4. Provide central pump for supplying lubricant to system.

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Handles difficult multiple-bearing lubrication under all conditions. Fully sealed for clean lubrication of power shovels, cement kilns, conveyors—any outdoor or indoor installation. Operates whether completely immersed in fluid . . . covered by dirt or grit . . . or protected by anti-corrosive paint. For fluid oil or light grease. Four sizes, delivering from .050 to .500 cu. in. of lubricant.

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Lube Lines

by A. F. Brewer*

Forced Shut-Down: A Costly Procedure

WHEN any piece of production machinery has to be shut-down unexpectedly for any reason, the cost of the "time-out" period usually can be calculated in terms of the dollar value of the loss of production. Wear is bound to occur in certain parts of any mechanism; it can become especially severe where lubrication has been inadequate either due to using a non-effective lubricant or to an inefficient means of application. The cost of any shut-down which is directly attributed to faulty lubrication generally can be regarded as an unwarranted expense because it is due to factors which normally should have been corrected during check-up. Loss of a thousand dollar bearing in steel rolling is serious enough, but loss of the steel tonnage which results while the mill is down for bearing replacement might have a vital effect upon the ability to meet a contract date and upon the operations of another industry which is to use the steel.

The wear and tear demands upon production machinery today are becoming more and more severe as units are speeded up and often over-loaded to meet production schedules. Machinery builders design to meet these requirements by devoting greater attention to uniformity in metal hardness, closer tolerances, and utilization of modern methods of automatic application of lubricants. The petroleum industry studies the prospective intensity of the operating conditions and the metals involved, and produces lubricating oils and greases containing suitable additives to withstand load and to retard the tendency toward oxidation, rusting, or corrosion. When operating machinery can be used as a proving ground to determine the suitability of any such lubricant for the service involved, data often can be developed which will be invaluable to the lubrication engineer and to the plant maintenance personnel. Also, these data often can be useful to the machinery builder in planning for future applications of automatic lubricating systems best suited to the design and conditions as a whole.

The term shut-down, of course, must be considered according to the cause. There are the usual routine shut-downs of a machine, or possibly the entire plant, for adjustment, inspection, and cleaning. There also are the periodic machine shut-downs for lubrication. It is the forced unexpected shut-downs, naturally, which are of most concern to management.

When an unexpected shut-down is made necessary due to faulty lubrication it may be on account of:

1. Using a non-effective lubricant.
2. Using an excess of a suitable lubricant to cause leakage and contamination of the product being processed.
3. Using insufficient lubricant so that "starved" lubrication results.

*Consultant, and author of *Basic Lubrication Practice.*

Items Involved When Shut-down Is Necessary	How Operation or Costs Are Affected	Time Loss Hours	Estimated or Calculated Cost
Production	In terms of output		
Plant Procedure	Adverse affect on related plant machinery. (Slow-down or actual stoppage)		
Repair and maintenance costs	Cost of parts renewed Cost of labor for renewal		
Labor	Operators for idle machines must be released or detailed to other duties		
Specialty Service	Expert labor or supervision required (beyond plant facilities) to get things running again		
Overhead	Must go on as usual, even though production is curtailed		
Utilities	Must be maintained as usual, even though production is curtailed		

The proper grade and type of lubricant are determined by thoughtful purchasing in consultation with plant operating personnel and a capable lubrication engineer.

Use of lubricant either in excessive or insufficient amounts depends upon how automatic is the means of lubrication and how well trained are the operating people in regard to handling and controlling lubricating equipment. An excess of lubricant on any operating mechanism is unwarranted except where a totally enclosed gear set or crankcase is involved and splash or pressure lubrication of the component parts is developed by the dipping action of the gears or chains, or by a built-in oil pumping unit. With either design, most effective lubrication is assured where suitable piping, ducts or grooves are provided for circulation of the oil. In such systems the parts are flood lubricated. In other words they receive an excess of oil, an entirely satisfactory procedure where the oil sump and case are oil-tight and there is no chance for leakage.

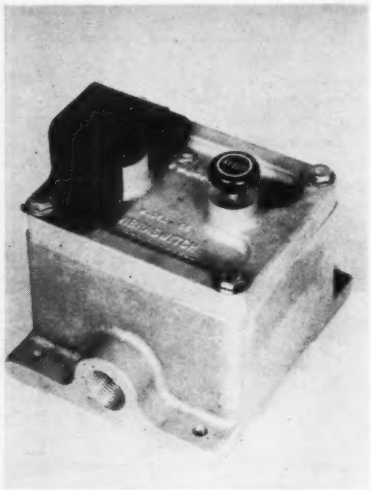
No particular type of lubricating system has a priority in preventing forced shut-down attributable to lubrication. Past history must guide the designing engineer when incorporating any means of oil, grease or solid lubrication in his plans. Past history also is most helpful to the plant personnel when purchasing and applying the lubricant required by the operating conditions and the lubricating system. If the latter is positive and designed for reasonable control of lubricant passage to the operating parts, the possibility of forced shut-down rarely will become an actuality.

A fairly accurate estimate of the probable cost of shut-down can be arrived at by considering the items shown in the accompanying chart.

New Products

QUICK-CHANGE PUMP SWITCH

A time and labor saver for sump pump users—a switch that will produce in excess of a million cycles—has been developed. Instead of having to return the entire pump to the factory for service, with this new quick-change switch the operator merely removes eight bolts, pulls out the old switch, and inserts a new one. Catalog sheets and price lists on the "Enpo" sump pump are available from the Piqua Machine and Mfg. Co., Piqua, Ohio.



FOIL-TYPE STRAIN GAGES

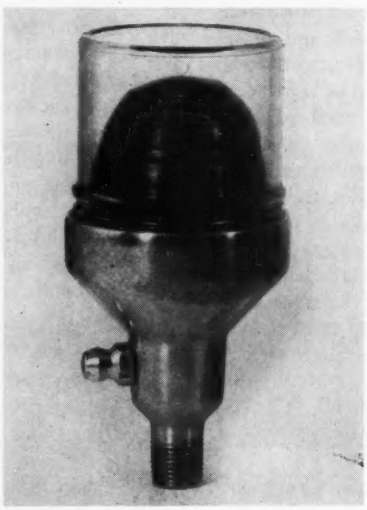
New SR-4 foil-type rosette strain gages reportedly with substantially higher sensitivity and stability than any previous rosette gages are now available. Of bonded filament construction, these rosettes have an increased sensitivity of eight per cent over previous rosettes. They need no lateral corrections except in the most precise testing problems, can withstand temperatures as high as 300° F in continuous service, and are thinner, more flexible and more easily applied than bonded wire SR-4 strain gages. Two sizes of bakelite bonded rosettes are available: Types FABR-2 and FABR-4, with gage lengths of ½ inch and ¼ inch respectively. For further information, contact Richard T. Biedler, Electronics & Instrumentation Div., B-L-H, Waltham 54, Mass.

LUBRICANT RESISTS CORROSION

Electrofilm, Inc. has completed a series of tests on its latest one coat "corrosion resistant" solid film lubricant 66-C, developed because of problems of lubricant failure caused by corrosion. In these tests, the lubricant met the requirements of Mil Spec (L-25504) without sacrificing either long wear life or frictional properties. Coefficient of friction of 66-C is less than 0.04, and the lubricant can withstand a 1300 hour salt spray test over anodized aluminum. This coating works as a dry film lubricant in temperatures ranging from —65 degrees F to 600 degrees as well as in exceptionally high loads and high speeds. For additional information, write for Electrofilm Technical Bulletin No. 2055 to Electrofilm, Inc., P. O. Box 106, N. Hollywood, Calif.

GREASE CUP DISPENSER

Greasing electric motors, pumps, blowers, shafts, fans and other machinery by hit or miss methods is said to be eliminated with Visiball automatic grease cups. The heart of the cup is a neoprene disc which can be inflated into a ball capable of holding up to two ounces of grease. The disc is filled with a standard grease gun through a fitting on the side of a chrome plated zinc alloy housing. Protecting the neoprene ball is a clear lucite plastic cylinder through which the maintenance man can see the ball as it fills with grease. As the bearing uses grease, the ball deflates indicating the quantity of grease remaining. It is not necessary to refill the cup with grease until the disc returns to the deflated position. Tests by the manufacturer show that undergreasing and over-greasing are eliminated, maintenance time reduced, bearing life prolonged, and machinery life increased. This device can be obtained from Visiball Mfg. Co., P. O. Box 7021, Ft. Worth, Tex.



ASLE MEMBERSHIP CLASSIFICATIONS

Membership in the American Society of Lubrication Engineers is in several grades as defined below. Assignment to grade is made by the Admissions Committee or Board of Directors on the basis of information submitted or supplied by references.

Members: Members shall be persons not less than 24 years of age who: (1) are engaged in research and instruction at technical schools, universities, and various publicly and privately supported institutions in the field of lubrication; or (2) have occupied recognized positions as lubrication engineers for a period of three or more (not necessarily consecutive) years prior to date of admission, involving the responsibilty for or supervision of the development, selection, field use and application of lubricants as differentiated from other activities; or (3) are indirectly concerned with the field of lubrication, but possessing other qualifications of experience, knowledge, and accomplishment, and have manifested a particular interest in the purposes and welfare of the Society to the extent that their membership would be a valuable contribution to the successful functioning of its activities. Fee $15.00.

Associate Members: Associate Members shall be persons less than 24 years of age, and those who do not completely fulfill the membership requirements for Members. Fee $7.50.

Sectional Sustaining Members: are such persons or organizations as may be interested in and desire to contribute to the support of the purposes and activities of a local Section of the Society. Fee $25.00.

Industrial Members: Industrial Members are such persons or organizations as may be interested in and desire to contribute to supporting the purposes and activities of the Society. Fee $150.00.

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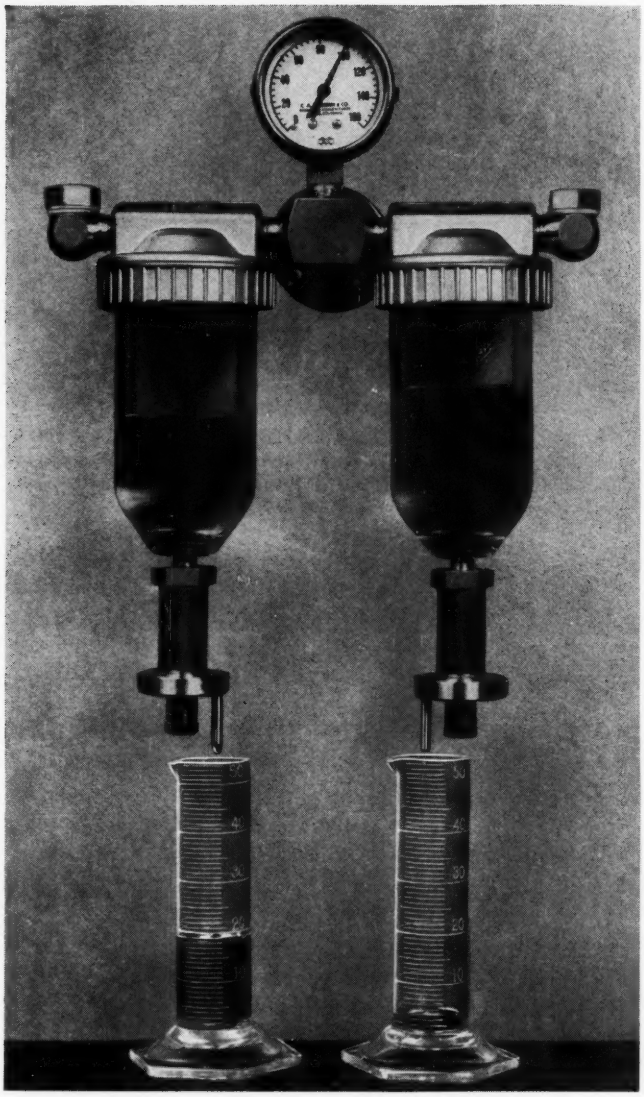

ANTILEAK DEMONSTRATION

Suntac oil in one chamber, your present hydraulic oil of the same viscosity in the other. Both oils are forced out through sintered bronze bearings. In this photograph, pressure of 100 psi caused a straight mineral oil to leak out four times faster than Suntac.

SUNTAC CUTS HYDRAULIC OIL LOSS AS MUCH AS 75%

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Have him arrange with a Sun Lubrication Engineer to give you and your staff a private demonstration. For further information on the uses of Suntac in hydraulic systems and in general lubrication, write to SUN OIL COMPANY, Philadelphia 3, Pa., Dept. LE-11.

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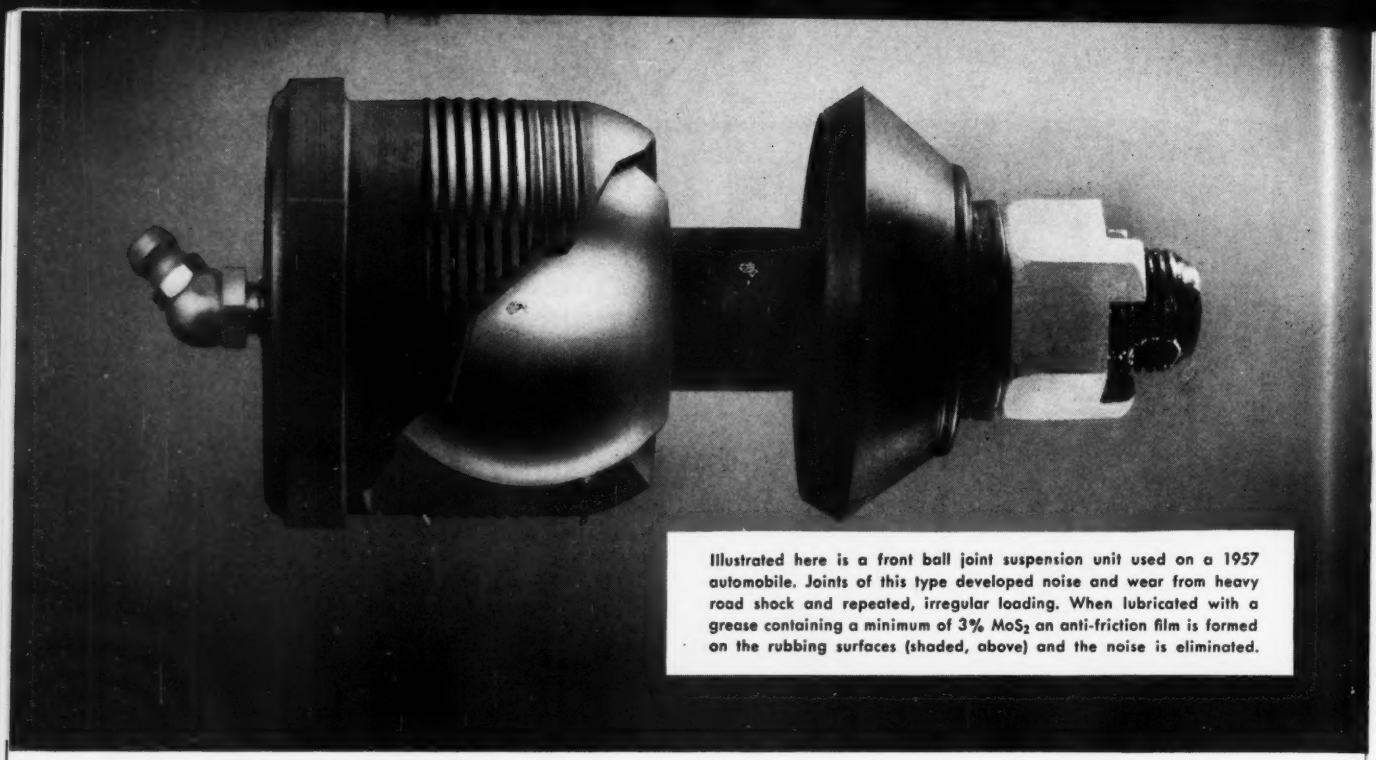


Illustrated here is a front ball joint suspension unit used on a 1957 automobile. Joints of this type developed noise and wear from heavy road shock and repeated, irregular loading. When lubricated with a grease containing a minimum of 3% MoS_2 an anti-friction film is formed on the rubbing surfaces (shaded, above) and the noise is eliminated.

When bearing surfaces are stripped of lubricants by SHOCK LOADING, OSCILLATION or RECIPROCATION . . .

MOLY-SULFIDE additive extends effective lubrication

Serious lubrication problems are often set up by extreme pressures, shock loading, oscillation and certain forms of reciprocating motion. Conventional lubricants may be forced out of the bearing area or wiped off the bearing surface. Then something more than a standard grease is required.

In situations of this kind, grease containing Moly-Sulfide proves its great value. MoS_2 is forced between the rubbing surfaces, adheres to the metal and forms a protective film that prevents galling, welding and fretting. The extent to which MoS_2 sustains lubrication is demonstrated by substantial reduction in wear, and is borne out by field reports from many different industries.

4 specific cases show advantages of MoS_2 for industry

Avoids splitting in steel punching. For example, while punching ⅝″ holes in ½″ thick hot rolled steel it was found that splitting of the plate frequently occurred between two adjacent holes, or toward the edge of the plate. This trouble, a result of heavy shock loading, was eliminated by brushing punches with lubricant containing MoS_2.

Makes excellent break-in lubricant for rocker arms. For break-in runs of engines, one of the major automobile manufacturers uses a supplemental MoS_2 grease on rocker arm pivots. The MoS_2 provides a low-friction film when the base lubricants wipe off under oscillating motion. This prevents galling and scoring of the mating surfaces.

Gives smooth travel to 4-ton grinding head. On a heavy cylindrical grinder the 4-ton head moves on the ways in a jumpy fashion, resulting in damage to the work. Use of a lubricant containing MoS_2 results in smooth, precise travel.

Serves well where lubricant cannot be resupplied. Moly-Sulfide is now widely used for lubricating such hard-to-reach points in automobiles as convertible top mechanisms, power operated windows and seat adjusters. Applied at assembly, the MoS_2 extends lubrication and greatly reduces noise and wear.

Many manufacturers now producing MoS_2 greases

Moly-Sulfide greases are available from many producers today. For a list of the manufacturers of these greases (Lu-2a) – which includes several major oil companies – and for a copy of "Molybdenum Disulfide as a Grease Additive" (Lu-17) write to Department 38, Climax Molybdenum Company, 500 Fifth Avenue, New York 36, N. Y.

LUBRICATION ENGINEERING

RESEARCH APPLICATION EDUCATION MAINTENANCE

Cooperation—No, Dedication!

Let me tell you about a recent experience I had which illustrates the extent of cooperation that exists at the Section level. Recently a group of 20 members petitioned National Headquarters for recognition as a new Rochester Section of ASLE. Frankly, some of the officers and directors were skeptical. How much success could be expected from a Rochester Section located within driving distance from a strong and active Section in Buffalo and the nearby Syracuse Section, which has not had too much success in attracting industry cooperation and interest in ASLE? The petition was duly executed according to the by-laws, however, and approved by the board of directors.

I attended the indoctrination meeting of the new section October 9. At the meeting I discovered great enthusiasm, energy, and ability at the local level. More than 50 members, guests, and well-wishers were present, including two past presidents of the Society, the president-elect, the Eastern regional vice-president, the administrative secretary, and several past directors of ASLE. The success of this first meeting should set an example for those who say, "But why should I join ASLE? There's no Section organized within 300 miles."

We asked members from the Buffalo Section if they would not object to having a new Section attracting members and potential members from the Buffalo roster. Rather than object to having a rival Section, Buffalo gave the Rochester Section its blessing with a cash donation of 200 dollars.

This spirit that causes our members to place the goals of ASLE ahead of personal gain can no longer be called cooperation, but must be called dedication

—dedication to the goals and purposes established by the founders of ASLE—a professional level for lubrication technology

—dedication which makes it possible to welcome our 3000th applicant for membership: Mr. K. M. De Souza, application engineer for Esso Standard, S.A., Trinidad, British West Indies.

Perhaps each of us should determine our motives for being a part of ASLE. Then, by all means, we should do our part to further these goals to which we subscribe. We should make the example set by the members of the Buffalo Section a personal work day goal—a goal of cooperation, no, dedication, to spread the word of ASLE.

J. O. McLean
President

A Lubrication Engineer Surveys Steel Mill Gearing—I

A. E. Cichelli, Bethlehem Steel Co., Bethlehem, Pa.

PART I

Gear life for periods as long as ten or even 20 years is the hope of every maintenance man in the steel industry. This is not a dream — there are many examples of such performance where gears have been properly lubricated and ample safety factors built into the original design. Many such gears have been lubricated throughout years of service without the benefit of modern extreme pressure lubricants. In many instances, loads and speeds have been increased, and in a great many cases lead naphthenate type lubricants have been substituted for the original oil. On the other hand, there are numerous units still operating successfully on straight mineral oil. The logical conclusion seems to be that gear life depends more on original design than on choice or type of lubricant.

Even so, problems in steel mill gear operation have harassed the lubrication engineer as well as the lubricant supplier for years. To meet more severe operating conditions, more dependable lubricants of greater durability have been developed. Modern high stability, anti-rust and excellent demulsibility circulating oils are typical examples, followed by those fortified with lead naphthenates, generally classified as mild EP oils. Simultaneously, various active extreme pressure additives for use in such oils were perfected: compounds of sulfur, phosphorus, chlorine and fatty oils in various combinations. Introduced as anti-weld and wetting agents, they have become quite popular in the industry. Even solid lubricants have been proposed as additives to reduce scoring and extend gear life.

In spite of these advances in the development of lubricants, problems in gear lubrication still haunt the lubrication engineer and hamper his efforts to retard gear wear. These present remarks will be confined to the major driving units since it is felt that as a whole they are not standing up too well under present day conditions. Possibly this is the price we must pay for increased production. Possibly the economics may, in the end, justify the sacrifice of such equipment. The more frequent outages and high replacement costs, however, require that the matter be reviewed in order to seek a solution to this problem. The present trend of accelerated failures must be arrested.

With this thought in mind, the author has reviewed a cross section of examples of gear units in mill operation with which he is familiar, attempting to analyze their performance in the light of conditions as they were found. One theme predominated. Gear geometry and metallurgy are vitally important in influencing gear life — perhaps more so than the lubricant itself.

GEAR TOOTH ACTION

Gear tooth action involves both rolling and sliding. Friction is a function of their relative amount and the extent of load. The higher the rate of sliding, as in a worm gear, the greater the frictional heat. A spur gear under the same load would generate less frictional heat. Sliding causes the oil film to be sheared at every point between meshing teeth, except at the pitch line where pure rolling takes place. To obviate actual metallic contact, the teeth at this line must be continually separated by a film of oil, presumably a thin film under tremendous load. Pressure-viscosity effects and possibly formation of a squeeze film may also be important factors in keeping tooth surfaces apart. Certainly all the elements necessary for these phenomena are present, perhaps accounting for the success which has been observed with some of the light oil applications.

That a hydrodynamic film actually exists between gear teeth even under very severe conditions is apparently no longer disputable. Equations have even been suggested for calculating film pressure, assuming perfect geometry. Recently[1] radioactive gears were run on straight mineral oil as well as EP oils, indicating that up to a specific load, there is no wear with either product. The slightest metal transfer would have shown up in the oil. Obviously, the teeth were kept apart by a hydrodynamic film. Beyond the critical load, metal transfer with both types of lubricants was experienced. With mineral oil, wear was in the form of scoring; with the EP product, wear was slower and in the form of chemical corrosion.

And yet, field practices and service conditions exist, pointing up the error of blindly following design formula. Careless mounting or bearing wear may lead to misalignment causing excessive loads on gear teeth. Undercutting and interference are also serious geometrical difficulties that should be avoided. Tip relief is often provided by beveling or rounding off sharp tooth edges to prevent one tooth from digging into the other.

In a steel mill, there are thousands of gears, large and small. The small ones can be troublesome in isolated cases, but usually most of those that are heavily loaded are well designed and adequately lubricated. When unusual wear does develop in a small unit, one usually finds

that poor sealing has permitted entry of scale and water, or that unexpected loads have been applied beyond the capacity of the unit. Mill table drives are examples of this type. Maintenance of small gears represents a high overall expense item because of the number, although this is easily handled as a regular item on repair turns. Seldom do these auxiliary drives cause major delay.

MILL DRIVES

The most serious offenders are the mill drives and pinions through which all the horsepower required in the actual rolling of steel is transmitted. This power source is usually a motor designed to withstand considerable overloadings — in many mills, as much as 225% at times. Essentially, this means the torque delivered through the gearing to the mill is considerably more than corresponds to the rated horsepower. Similarly, in mills driven by steam engines, torques are sometimes sufficient to stall them. Very high loads can result from difficult sections, special steels, low rolling temperatures and/or excessive drafts. Naturally, the gearing required to transmit this extra power must be capable of handling these peak loads.

Lest it be assumed high loads are exceptions, it is well to emphasize that many mills virtually are continuously operating close to the top of the motors' overload capacity, though each individual occurrence may last only for a few seconds at a time. There is nothing inherently wrong with this practice as far as the motor is concerned since it is designed to permit it to function in this manner. The fact must be recognized, however, that the gearing, subject to the same conditions, should also be designed to withstand these higher loads which, though they exist for brief periods, are of very high frequency.

Incidentally, where flywheels are used, loads on gear teeth are considerably greater than those indicated on meters. The difference in the amount of energy given up by the flywheel may be appreciable. Obviously, this is a factor which must be considered in the design and lubrication of the accompanying gear drive.

TYPES OF ROLLING MILLS

Rolling in steel mills is accomplished on both hot and cold stock. Mills which reduce hot steel, usually above 1800°F., are constructed to make relatively sizeable drafts (section reduction per pass) at these temperatures. If temperatures are permitted to drop, rolling loads may be markedly increased. Mills which reduce cold steel are used in the production of sheet and tinplate. Inasmuch as this steel is at ambient temperatures, drafts are comparatively small, but as might be expected, loads are quite high.

Let us consider first the mills that roll hot steel. The largest are the blooming and slabbing mills. Note that in these mills, the steel is reversed after each pass and hence the gears between the motor and the mill must reverse also.

Bloomers and slabbers are driven by large mill motors, 7000 hp for example, or by huge reciprocating steam engines. Torque is transmitted to the two driving rolls through a 1 to 1 ratio gear drive, better known as mill pinions, and connecting spindles. A separate motor drives the two vertical rolls on the slabbing mill through suitable line shafting and bevel gears. The mill pinions which drive the horizontal rolls are usually of double helical type with coarse pitches, such as 0.4 DP to 1. DP. Their pitch diameters give the mill its designation, i.e. a 54 inch blooming mill has pinions with 54 inches pitch diameter. Besides the fact these mill pinions reverse, thereby using both tooth faces, their shock loads are very great and frequent. Breakers trip out on these motors at 225% overload although, while meter readings are repeatedly near this value, the overloads usually are of momentary duration.

In addition to these typical heavy mills, there are other single-stand units such as plate and heavy structural mills, which employ speed reduction gears as well as mill pinions to transmit power to the mill rolls. Though steel is reversed on these mills as in the others already described, there is one exception, the 3-hi mill, in which the rolls (hence the gears) do not reverse. Pinions and drives in these mills are subject to shock and heavy loads just as in the heavier duty mills.

The next classification is the continuous mill. Continuous mills are either driven separately by individual motors, gear reducers and mill pinions, as in hot and cold strip mills, or they may be driven in multiple units as in rod, bar or billet mills.

In continuous hot strip mills, there are ten or 11 stands in sequence having their own gear reducers and pinions. Although surface speed increases from stand to stand until delivery speed out of the last stand is 1800 feet per minute or more, the load is divided up between each stand by predetermined mill settings. Since load is a function of draft, steel temperature, steel composition and speed, good judgment and co-ordination are required to obtain the best load conditions for each stand. Ordinarily, roughing stand loads are of a higher order of magnitude than finishing stand loads. Pinions and drives in the latter are subject to moderately heavy loads at high speeds and sustained periods (as the strip elongates), whereas those in the roughing stands must withstand very high impact loads for relatively short periods.

In a cold strip mill work rolls are driven by gear reducers (or increasers) and mill pinions, or even by pinions alone without reducers. These mills operate from medium to very high speeds, some delivering steel at rates of over a mile a minute. Gear difficulties in these mills do not result so much from shockloading as they do from a combination of sustained heavy loadings and the dissipation of heat generated during the very high peripheral speeds that are reached.

MILL LUBRICATION

Lubrication technique as applied to mill pinions and drives throughout the steel industry is essentially standard, though the same cannot be said of the lubricant itself. Very wide, and even amazing, variations in viscosity and quality are used on similar applications. Nor can one predict performance by evaluating the lubricant alone; we have experienced too many cases of good results with "poor" lubricants.

As for application methods, nearly all modern pinions and drives make use of an automatic circulating oil system, with sprays directed towards the line of mesh of the gear teeth. This applies to nearly all modern mills, the single stands as well as the continuous mills, some of which have stands several hundred feet apart. Most older mills employed bath circulation, each pinion or drive dipping in a bath of lubricant to serve as a circulating medium. Others designed with open gears are lubricated

with tacky compounds, either with or without EP additives. Where possible, many plants are converting to circulating oil.

Definite advantages are offered by the circulating system, particularly where contamination and heat must be counteracted. Such systems circulate oil to multiple units and return it to the storage tank where it can settle for at least half an hour before being returned to the individual points of lubrication. High speeds and loads generate a great deal of heat and a circulating system equipped with an oil cooler is the best way to keep it under control.

Abrasive foreign matter such as mill scale, along with water, can enter pinion housings due to their proximity to the mill. This is removed by the filters or strainers which form part of the reconditioning system, thus insuring that clean oil is returned to all points of lubrication. Regular inspection must be made, not only to be sure that any such lubricating and reconditioning system is functioning effectually, but also to afford opportunities to look for minute steel particles, almost a certain indication of gear wear.

Generally speaking, oil should be directed in copious quantities onto the faces of gears as they come into mesh. Usually, specially designed nozzles are used for this purpose so that flow patterns from individual nozzles overlap, completely enveloping the teeth. Rates of flow vary widely. The only flow criterion is that the gear be kept cool. Incidentally, there have been several instances of spray applied on the outgoing mesh for high speed operation. In some cases gear box temperature was reduced, but there was also an instance of increased vibration until oil was restored to the incoming mesh on a rod mill drive.

GEAR DESIGN THEORY

For a better understanding of this subject, a short survey of the literature is desirable. Many papers are available covering the theoretical aspects of gear lubrication, gear design, and gear metallurgy. Unfortunately, steel mill gearing has not been too widely studied. In the past, design theories have been verified only on relatively small gear test stands. This was done, for example, by the ASME Committee headed by E. Buckingham[2], whose work provided means for determining wear criteria for spur and helical gearing. These formulas have been modified to become the basis for much of the AGMA gear design criteria. However, none has received wide acceptance in the design of steel mill gearing. The latter are coming in for special attention at the present time by the AGMA, giving us hope that this special problem may be closer to solution[3].

Buckingham's technique[4,5] recognized the relative importance of tooth geometry, machining accuracy, gear hardness, and speed. Constants employed in the equations were obtained empirically from numerous test runs conducted by members of the committee. Where this approach applies, it is possible to predict load capacity of a gear governed by wear, and thereby determine whether the anticipated load will exceed it. To be adequately designed, the computed limit load for wear must exceed the dynamic load, which is greater than the tangential tooth load by a factor predominantly influenced by speed, materials and tooth error. This is independent of the type of lubricant used, although it is recognized that a lubricant must be present to lubricate and keep gears cool.

Buckingham's approach is based on the more fundamental work of Prof. Hertz in 1886[6]. Equations developed by Hertz for determining the compressive shear stresses between two cylinders in loaded contact have been modified and applied to gear teeth. Hertz's stress equation is actually an indicator of resistance to local compression and may be related to pitting type failures. Buckingham's tests, however, enabled him to include wear-type failure within the scope of his modified formula. Forms of wear other than pitting may be relieved by EP oils if such wear involves surface welding. Failure due to pitting cannot be helped by EP oils. In addition, there is a form of wear involving plastic flow of material which also cannot be helped by EP lubricants.

In applying the Hertz equation, it is obviously important to know how many teeth are carrying the load at any time, and at what point on the face of the tooth the worst condition exists. Theoretically, there are two places, (1) at the instant of initial contact where the root of the driving tooth is highly stressed and (2) at the instant of final recession when the tip of the driving tooth and the root of the driven tooth are highly stressed. If, during either instance, the load is carried completely by a single pair of teeth, we have the worst possible condition. Buckingham[4] points out, however, that there is less evidence of wear in the dedendum or addendum areas than at or near the pitch line. This, he reasoned, was due to bending at the tip, thus transferring the effective load elsewhere on the tooth. Therefore, application of Hertz's equation was made to apply to the pitch line radius of curvature. Furthermore, since a single pair of teeth will carry the load a large percentage of the time, the wear criterion assumes that all the load is carried by one pair. As mentioned, these equations establish a critical maximum safe load beyond which excessive wear takes place. These are based on maximum specific compressive stresses of about nearly twice the elastic limit of the weaker material; its degree depending on the susceptibility of the steel to cold working. Thus, limiting load for wear:[4,5]

$$W_w = D\, f\, K\, Q$$

where: W_w = Limit load for wear — lb.
D = Pinion pitch dia. — inches
f = Face width — inches
K = load stress factor —

$$\frac{S^2 \sin \phi\ (1/E_1 + 1/E_2)}{1.40}$$

ϕ = Pressure angle of gear teeth
E_1, E_2 = Modulus of elasticity of materials in pinion and gear — psi
S = Maximum specific compr. stress—psi
Q = ratio factor = $\dfrac{2N_2}{N_1 + N_2}$
N_2 = number of teeth in gear.
N_1 = number of teeth in pinion.

In determining W_w, one must realize "K" is based on empirical results obtained after numerous test runs on a fatigue testing machine of two cylinders in loaded contact. Essentially, W_w represents the equivalent static tooth load in a pair of gears as that applied between two cylinders with the same radii of curvature and moduli of elasticity as the gears in question, that load corresponding to the safe endurance limit of the cylinders.

Admittedly, use of such data until now has been limited to smaller, more precise gear sets than are discussed here, but we hope to show that we may be justified in their use for large units.

The equation for "K", the load stress factor, is a modification of the Hertz stress equation for two rolling cylinders in loaded contact.

The formula for dynamic load (which is compared with the above limiting load for wear) makes allowances for the effect of speed (pitch line velocity), materials, tooth form and expected errors in manufacture. Based on Buckingham's committee work, for spur gears, it is:

$$W_d = W + \frac{.05V\,(fC + W)}{.05V + \sqrt{fC + W}}, \text{ where}$$

W_d = Dynamic load, lb.

W = Tangential tooth load — lb. $= \dfrac{33{,}000\ Hp.}{V}$

Hp = Horsepower transmitted.

V = Pitch line velocity — fpm.

f = Face width — inches.

C = Deformation factor, a constant, based on tooth form, precision in manufacture and the moduli of elasticity of the mating materials.

Similar equations have been developed for helical and double helical gears, and include the modifications caused by the effects of the helix angle, ψ.

$$W_w = \frac{D\,f\,K\,Q}{\cos^2\psi}$$

$$W_d = W + \frac{.05\,V\,(fC\cos^2\psi + W)\cos\psi}{.05\,V + \sqrt{fC\cos^2\psi + W}}$$

There is one more basic design approach to be considered and that is to insure the adequacy of the tooth's beam strength. It is evident that a gear tooth is really a cantilever beam, fixed at one end with a varying load applied progressively from its root to its tip and vice versa. On a helical tooth, the load also fluctuates along its length as it comes into mesh with the mating tooth. The well-known Lewis formula has been used successfully, taking the following form:

$$W_s = S\,p\,f\,y$$

Where: W_s = Safe bending load on gear tooth — pounds

S = Safe static bending stress (flexural endurance limit) — psi

p = Circular pitch — inches

f = Face width — inches

y = Tooth form factor (tables available) [4,5]

A stress concentration factor, "β", related to the fillet radius at root of tooth is introduced, giving:

$$W = \beta\,S\,f\,p\,y$$

The formula considers the entire load to be carried at the top of the tooth. However, due to either elastic deformation or tooth error, the load will very likely come into play lower down toward the middle of the tooth. Depending on the contact ratio, for short periods, one tooth is carrying the entire load.

Helical gear beam strength is calculated similarly, although because of the angular contact line, the ends of the teeth are subject to a higher momentary stress at the beginning and ending of the meshing. However, because of elastic deformation, a second pair of teeth will come into contact almost instantaneously, helping to share the load. In helical teeth, the tangential load normal, or perpendicular, to their face is greater than the tangential load in the plane of rotation; but the developed length of face width exactly compensates for this increase since it is greater by the same ratio.

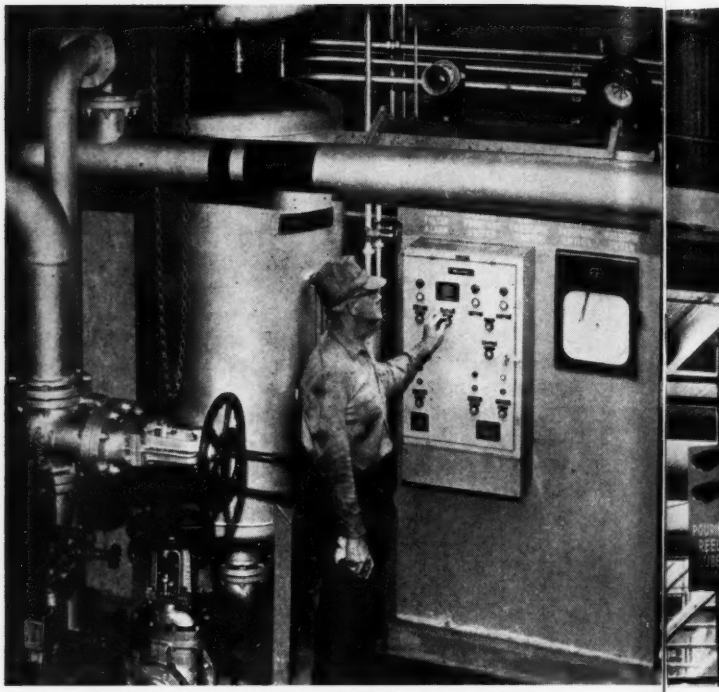
There are other aspects of gearing that have come under the designer's scrutiny, such as effect of impact, torsional deflection, tip interference, surface, finish, etc., and each has been recognized and adjusted for in the average application.

Obviously, the simplicity of the Buckingham and Lewis equations make them highly attractive for the design of steel mill gears. However, it must be recognized that the constants were all obtained empirically and compiled for gearing different than ours. To collect sufficient data from large steel mill drives for the same purpose is obviously a most difficult job. Buckingham's formula tolerates a maximum error in action of about 0.005 inch. For our large units, this would be too optimistic, so that it becomes clear the formula cannot be applied blindly. Because of the lack of reliable steel mill data, the establishment of appropriate criteria has been held in abeyance.

Too often, the prevailing practice has been to rely on past experience, to study a previous similar application and hope for the best. Sometimes the results were good; but just as often they are not. We feel that, in view of the ever-changing, ever-increasing demands placed on existing and new equipment, this procedure is risky and a more dependable one should be developed and followed.

One conclusion to be drawn from the work of Buckingham is that, if gear materials and geometry are adequate, there should be less pitting, less wear, and therefore less need for other than straight oils. From a cost and security viewpoint, this should be an ideal to be sought. A drive that requires an extreme-pressure oil to prevent wear presents an undesirable situation as there is less margin of safety available to accommodate changing conditions that invariably produce even greater loads. Despite this seemingly basic principle, its universal acceptance will never come about until design criteria are agreed upon. Because there is no existing design criterion for our large gearing, we have applied Buckingham's wear and dynamic load formulas and compared their predictions with actual results. Some of these specific studies will be discussed in Part II of this paper, to appear in the next issue of *Lubrication Engineering*.

Custom E-P Installation Services High Speed Drives



This partial view of the main oil cellar at Atlantic Steel shows the control panel for one of the main lubrication systems. This panel contains master signals for those on the main signal board mounted on the wall on the mill area. Next to the control board is an automatically and continuously cleaned constant-pressure-drop type filter.

Three circulating systems provide effective lubrication for new steel mill

HEAT—generated on gears and drives of a high speed steel rolling mill by its tremendous pressures—demands continuous flow of proper lubricants under close temperature and pressure controls.

To handle this taxing job, three custom-built mill lubricators feed approximately 475 gpm of EP oil in various viscosities to gears and bearings on drives of a new merchant bar and rod mill of the Atlantic Steel Co., Atlanta, Ga.

Recently placed in operation, the $9,000,000 mill is rated as one of the world's fastest combination units. It is capable of producing three strands of rods simultaneously at a delivery speed of 5,000 feet per minute and can produce merchant bar in a wide range of sizes and shapes at rates from 30 to 80 tons per hour.

Billets ranging in sizes from 2½ inch squares through 7 × 3 inch slabs—25½ to 31 feet in length—are reduced in size to products ranging from No. 5 wire rod (0.218) through 4 inch angles or equivalent cross sections. Billets leave the furnace and enter the roughing mill at approximately 25 feet per minute.

Lubrication of the mill is regulated by 327 built-in orifices which assure distribution of lubricant in proper quantities to the numerous points of use and eliminates the need for external sight feed. Of this total, 258 orifices supply oil to individual bearings and 69 provide lubricating sprays at gear mesh points.

Lubrication systems, including design of cellar and piping layouts, were supplied by Dravo Corporation, Pittsburgh, in accordance with detailed engineering specifications of Morgan Construction Co., Worcester, Mass., who designed and built the mill machinery.

The smaller of the three mill lubrication systems supplies 22 gpm of 1,000 SSU oil at 100° F to gear drives operating the billet cross pushers for the gas-fired reheating furnace. Gears for these drives are enclosed in two separate housings with their sumps serving as reservoirs for the lubricating oil supply. Oil returning to the pump from the reservoirs passes through the pump suction strainer. After being brought back to the desired pressure, the oil passes through the main system filter to remove any foreign particles before returning to the drives.

Pressure and temperature are both indicated in the smaller system by instruments on the drive platform, and signal lamps at the charging pulpit of the furnace provide operating personnel with a visual indication that the system is operating and proper lubrication is being maintained. Two larger lubrication systems supply oil to the main gear drives, pinion, and auxiliary equipment. The mill has 21 roll stands, 15 of which are used when rolling merchant bar sections. All stands are required for smaller diameter wire rod production.

A large signal panel mounted above the mill floor directly opposite the mill pulpit provides immediate notice by means of lights and audible alarms of an oil pressure failure in the lubrication system. Controlled by low pressure switches at each lubrication point, the signals enable personnel to pinpoint the nature and exact location of trouble.

One of the larger systems supplies 230 gpm of 1500 SSU oil at 100° F and serves the pinion stands, speed reducers, compact drives, and pedestal bearings for the roughing and intermediate mill stands. The other large system, supplying 220 gallons of 800 SSU oil per minute at 100° F, has a two-branch operational arrangement.

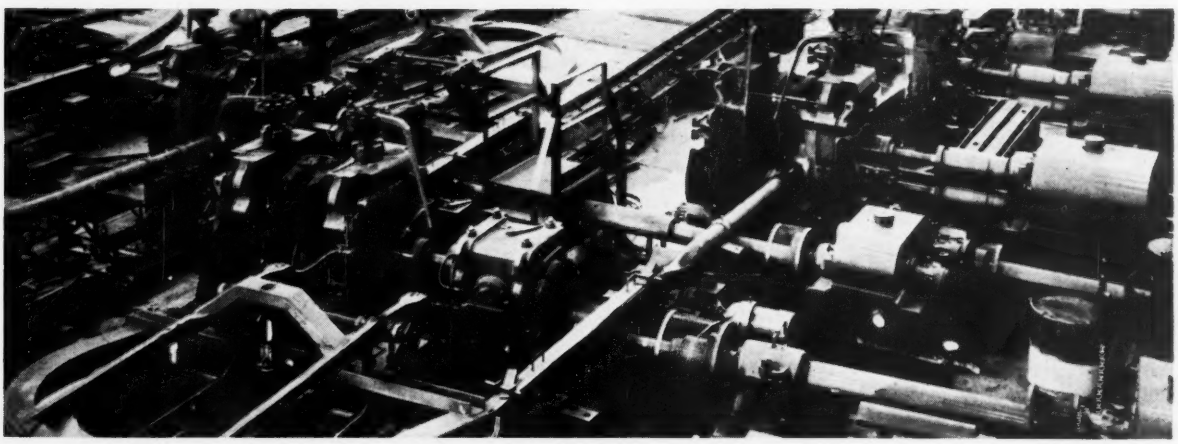
Branch C-1 is used when merchant bar is rolled. Branch C-2 is operated in conjunction with Branch C-1 when all 21 stands of the mill are in operation during the rolling of rods. C-1 lubricates gear reducers, drum shear drive, pedestal bearings, and pinions on stands 8 through 15 while C-2 lubricates pouring reels, coil conveyor and laying reels, and compact drives for the rod finishing mill. C-2 is equipped with an automatic pump system to return oil from low points which do not permit return flow by gravity into the main reservoir. Indicating lamps for this return system are mounted on the main signal panel.

Connected into the two larger systems serving the mill are 14 pressure reducing stations to regulate oil pressure to the various orifices. Constant pressure is so important that pressure switches at each pressure reducing station control signal lights and a warning horn on a large signal panel above the mill floor located directly opposite the main mill pulpit. A siren and lights on the signal panel serve as alarms on the main system pressures and reservoir oil levels.

From the green lights on this signal panel, mill personnel are assured that the lubricating systems are functioning and that all machinery components are being supplied oil at correct pressure and temperature requirements. Operating conditions of both systems are shown on control panels in the main oil cellar.

The two larger lubricating systems have been designed to provide continuous 100% filtration of the oil and to automatically maintain the required flow capacities, operating temperature, and pressure of the lubricating oil.

Overall view of merchant bar and rod mill, Atlantic Steel Co., Atlanta, Ga.



Journal Box Lubrication

H. D. Plumly, Baltimore and Ohio Railroad, Baltimore, Md.

The standard AAR journal bearing was adopted in 1874. So effective was the basic design that it has been difficult to improve upon it. The plain bearing assembly is of relatively simple construction, shown by Figure 1. The internal parts are bearing, journal and wedge. The box provides the housing and also acts as an oil reservoir. It is closed at one end with a spring loaded lid and at the other end with a dust guard.

The bearings, fabricated as cylindrical segments, consist of a brass back and babbitt lining. They are commonly referred to as "brasses" in railroad language, but their composition is as listed:

BACK

Lead, %	15/22
Tin, %	4.5/6.5
Zinc, %	2.5/4.5
Impurities, % Max.	1.0
Copper, %	Balance

LINING

Tin, %	As Specified
Antimony, not less than, %	8.0
Tin and Antimony, %	10/14
Arsenic, % Max.	0.2
Copper, % Max.	0.5
Sum of Tin, Antimony, Lead and Arsenic, % Max.	99.25
Remainder, % Max.	0.75

We like to refer to the back as a "leaded bronze". The babbitt lining provides the bearing surface and is easily conformable with the journal. The wedge serves to distribute the load and to help seat the bearing properly.

The bearing is lubricated by oil which is fed to the journal from the bottom of the box by capillary action of a wicking medium. When operating with a sufficient supply of oil, the bearing is separated from the journal by a wedge-shaped, load carrying oil film.

Advantages of this type bearing are: ease of removal and application, low cost, and the ability to survive abuses heaped upon it. These abuses do not appear in the form of loading (a maximum of 784 pounds per square inch) or journal rotational speed (a maximum of 20 feet per second). They appear in lubricant contamination from inadequate sealing, short inspection and maintenance time due to rapid train movements in classification yards, short bearing wear-in periods from the rapid acceleration possible with diesel powered trains, the long periods of standing when business is slow, and finally, rigors of car impacts.

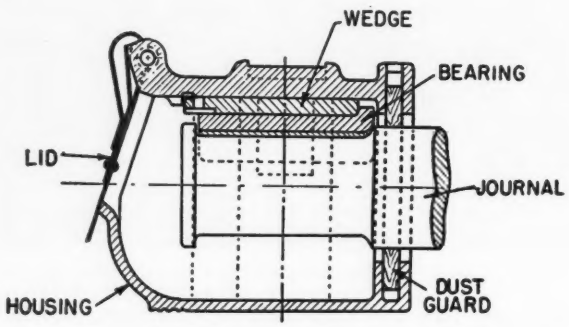


Fig. 1. Section drawing showing the main parts of a plain bearing railroad journal box.

HOT BOXES

A lubrication failure is commonly called a "hot box" in railroad parlance. The occurrence of a "hot box" is serious, because it requires the setting out of cars from trains for maintenance. Since this causes delays in schedules, it is costly. If hot boxes are not detected early they can lead to more serious damage to the bearing and axle.

As the name implies, a "hot box" ultimately occurs when more heat is generated than can be dissipated. That is, the normal heat balance between input and output is distorted. On the input side is the heat generated by the fluid friction from the viscosity of the oil in the clearance space between bearing and journal and secondly, the friction of the wicking media against the journal. A third source could be the friction of a positive oil seal at the rear of the journal box. This frictional heat is dissipated through the bearing, journal and flow of oil. A "hot box" occurs when the heat is not removed from the bearing assembly fast enough to maintain an optimum running temperature. A "hot box" is really a lubrication failure, regardless of how the failure was initiated.

STATISTICS

Statistics tell a story, so let's look at some. Figure 2 shows a summary of detentions due to freight car failures for the period 1946-1955. For convenience, they are broken down into two groups; the "hot boxes" and other

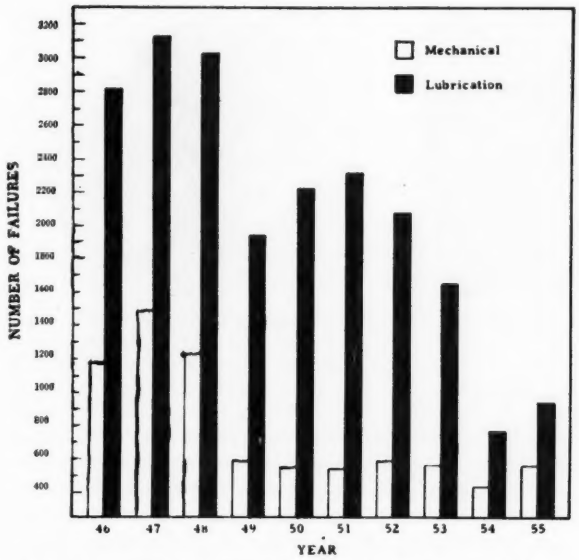


Fig. 2. Summary of detentions due to freight car failures. Mechanical vs. Lubrication.

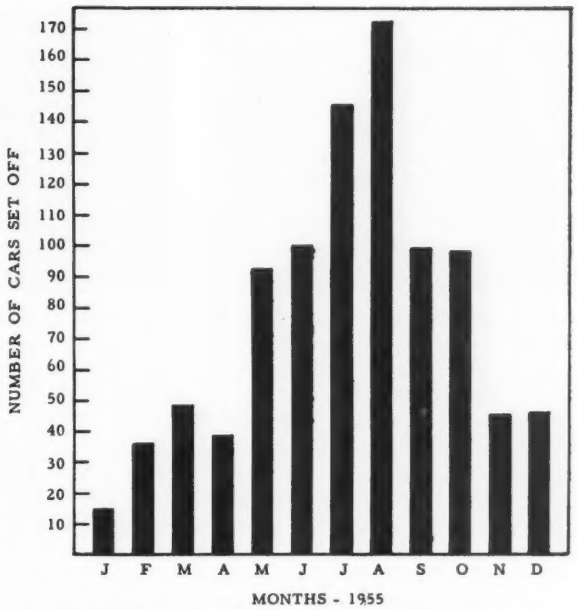


Fig. 3. Number of lubrication failures per month for 1955.

mechanical failures, such as brake rigging, broken knuckles, air brakes, etc. The ratio of lubrication to mechanical failures ranged from a maximum of 4.1 in 1951 to 1.7 in 1955. The mean for the ten year period is 2.7. This indicates the seriousness of the frequency of lubrication failures and it is no wonder that the "hot box" has been a major target for improvement for some time. It also indicates that improvement is being made.

Now that we have separated the lubrication from mechanical failures, let us look at a breakdown on the figures for lubrication failures for the year 1955. Figure 3 shows the number of lubrication failures per month. These figures show that the incidence of "hot boxes" is about three times as great during the summer months of May through September, with the peak occurring during July and August. While these are figures obtained from one railroad they are typical of the figures for all railroads, regardless of geographic location. Why this occurs is not known, but ambient temperatures have been advanced as a reason.

A CHANGE IS NEEDED

The cost of maintaining the present journal box is too great. One railroad employs 600 men maintaining and inspecting journal boxes in transportation car yards. The annual cost is about 3 million dollars. The costs of material and repairing damages caused by "hot boxes" are also significant. However, changes affecting 2 million freight cars cannot be accomplished rapidly; they must occur slowly. Therefore, in the interim some things can be done to help the situation with the materials and methods available. An example follows:

A CASE HISTORY

In order to change or alter any existing situation three things must be done. First, you must agree that it has to be done; secondly, find the best thing to do; and finally, do it. A good example is the record of "hot box" performance on one railroad once it had made up its mind to improve the situation. Probably no single factor alone was responsible for the improvement, but each contributed its share. Figure 4 shows the improvement. For comparison, where figures were available, the average improvement for all other railroads is shown. A study of the sequence of events indicates the following factors.

MATERIALS

In December 1942 a new car journal packing and oil reclamation plant was put into service on that railroad. The standards for quality of its products were set at the same level as those for new materials.

In January 1943 a chemist was employed and assigned with sole responsibilities for quality control over new and reclaimed car oil, waste for journal boxes, and packing actually running in journal boxes. The objective was to insure the best qualities in lubricating media. All tests were run regardless of their difficulty. There was no compromise where quality was concerned.

In September 1948 quality control over journal bearings was improved by employment of additional inspec-

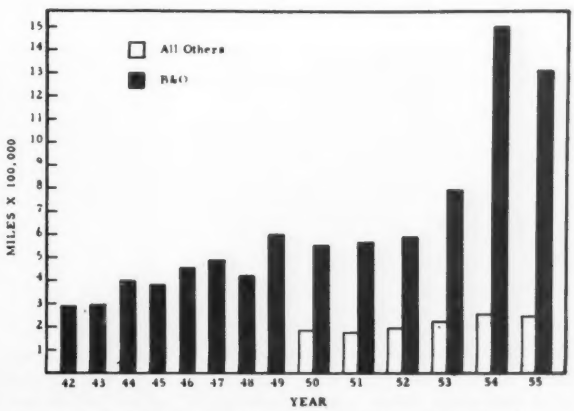


Fig. 4. B. & O. improvement vs. average of all other railroads.

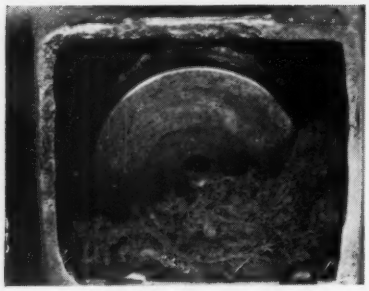


Fig. 5. Packing condition after 11.5 switching impact.

Fig. 6. Packing condition after 450 mile run.

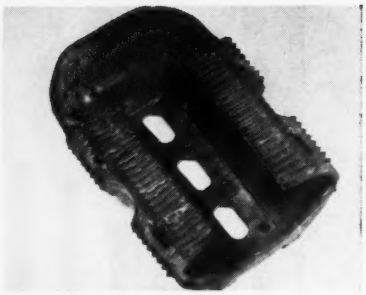


Fig. 7. Waste retaining device.

tors and establishing the rule that no bearings would be used unless individually inspected. In 1949, although the AAR specifications did not require it, the railroad started using a superior car oil of 105 viscosity index. In 1950 AAR adopted improved specifications for waste, oil and packing. Railroads also changed from winter and summer grades of car oil to an all year grade.

In 1953 the Institute of Thread Machiners, Inc. established a self-imposed quality control for waste for journal boxes and certified by affixing the seal of the Institute to each bale of waste guaranteed to be of AAR specified quality. This made a definite improvement in waste for box packing. Although it did not relieve the railroad from the responsibility of inspection, it greatly improved relations between the buyer and seller.

In 1955 the AAR specification for car oil was still further improved to give better viscosity characteristics over a wider temperature. Finally, their specification is still under scrutiny to determine if further improvement can be made in summer performance without sacrificing the good winter performance.

In the past the same bearings were applied to all undersize axles. On March 1, 1956, the prevailing loose fit or tolerances between solid journal bearings and axles were replaced by a system of controlled journal bearing clearances. Three sizes of bearings, designated as A-1, A-3 and A-5, have been adopted. The dimensions and tolerances of the bearings and journals will result in a clearance of 0.010 to 0.025 inches, while the old tolerance permitted a clearance of 0.125 inches. As fitted bearings will be applied on all new and rebuilt cars and in all repacked boxes it is expected that within a period of 18 months, the present repack period, a large percentage of existing cars will have the controlled-clearance bearing.

Methods

While serious reflection was given to the materials involved, considerable thought was also turned in the direction of some of the methods used in servicing the boxes. To aid in this study, in 1947 a Supervisor of Lubrication was appointed by the railroad with the responsibility of standardizing the procedure used in packing the boxes and teaching it to the supervision in the car department.

A study was made of the time required to inspect and service boxes in the car yards. A simplified procedure for setting up packing in boxes of cars in the transportation yard was developed and adopted as a standard for all points. It is commonly called the "B&O 9-Stroke" method. It involves nine simple strokes of the packing iron in a definite order of sequence which puts the waste pack in good running condition with the least consumption of time and effort. This resulted in a system which requires 15 seconds per box. A typical car yard team consists of six trained men; three inspectors and three oilers. Each inspector accompanied by an oiler takes a section of cars. It is "blue flagged". The inspector opens the boxes indicating which need attention. The oiler does the necessary work. A six man team handles about 68 cars per hour.

Records showed the locations originating the most hot boxes and adequate inspection and servicing was set up at those points. These records are maintained so that immediate attention may be directed to any point showing a marked increase in lubrication failures.

FUTURE ACTION

We have just reviewed what has been done using existing materials and methods. With these the expectancy

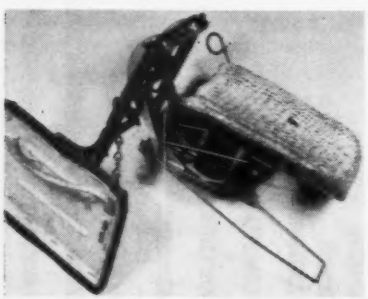


Fig. 8. Mechanical lubricating device. Shown is the pad which ideally is composed of a long staple fiber. Lint is minimized through the use of such fibers.

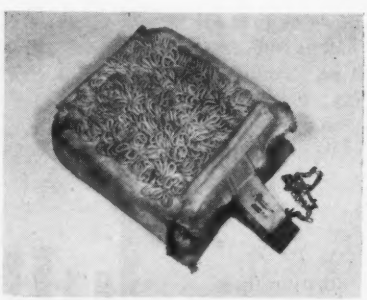


Fig. 9. Lubricating device—neoprene foam body sewn into cotton container with special weave yarn looped through entire assembly to wick oil to the journal along its length.

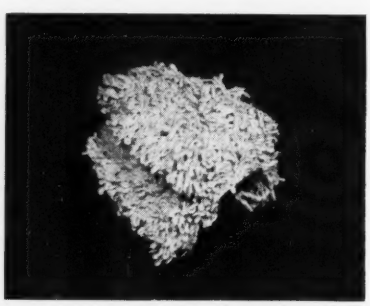


Fig. 10. Lubricating device — pad has two steel retainers into which are fitted two rolls of special blanket material, tied to give shape and act as wicking material.

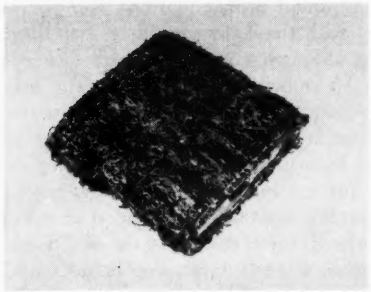


Fig. 11. Lubricating device — pad of rectangular shaped cellular core enclosed in tough blanket-like material made of threads and wicking cloth. Contacting journal and box bottom, this blanket wicks oil to the journal.

Fig. 12. Lubricating device — silicon-impregnated wool-felt wick covering tempered spring steel frame to feed oil to journal surface. Fillet oil seal and lid seal are built into the device which is bolted to the box just under the lid opening.

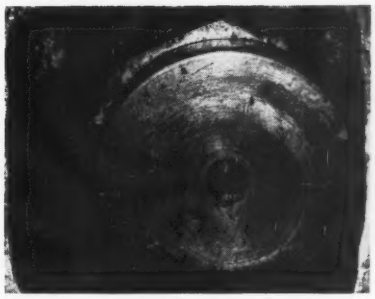


Fig. 13. Axle and bearing displacement at 11.5 mph impact. Closely allied with this is the shifting of the packing medium which can occur with either the waste or lubricating device.

of a hot box on the average freight car is now about one every 15 years. It appears that it would be difficult to improve on this, but let us look at what is happening.

It is a well-known fact that some shifting of waste usually will occur during "humping" as well as during normal operation of a freight car. Figure 5 shows an example of what happened to the packing after flat-switching impact at 11.5 mph. Figure 6 is an example of displaced packing after a 450 mile run. When the packing shifts, the journal may pick up waste threads and carry them between the bearing and journal where they cause localized high friction and hot spots which develop into bearing overheating and eventually a failure. Another problem with waste packing is that waste settles to the extent that the packing loses contact with the journal and no feeding of oil to the journal is possible. These deficiencies call for maintenance, and maintenance is expensive. Besides that, with the faster train movements time is also at a premium. In view of this the AAR has ruled that loose waste will be prohibited and an approved type of journal lubricating device must be installed on cars built new, rebuilt, or receiving heavy repairs after August 1, 1957. Effective January 1, 1960 all cars having plain bearings must be equipped with an approved type of journal-lubricating device.

Naturally this gave rise to tremendous activity in the development of lubricating devices. These have fallen into three classes: waste contained in retaining devices, mechanical lubricating devices, and pad type lubricators. Figure 7 shows an example of a waste retaining device. Figure 8 shows a mechanical lubricating device.

By far the greatest number of lubricating devices are of the pad type. The ideal lubricator of this type should be a non-metallic pad, highly resilient, and highly absorbent. It must have good capillarity and be non-abrasive, insoluble, with physical properties unaffected by oil or water, and acid resistant. It should remain unchanged through temperatures ranging from —40°F. to 375°F. It should be non-glazing, and it must not shed lint, fibres, or loose strands to adhere to the rotating journal.

A significant factor to be considered in the development of lubricating pads is the allowable limits within which they must function. Refer to Figure 1 and consider the condemning limits in a $5\frac{1}{2}'' \times 10''$ journal box. Starting at the top the allowable maximum wear figures are as follows:

Box Wear	$\frac{1}{8}''$
Wedge Wear	$\frac{3}{32}''$
Bearing Wear	$\frac{1}{4}''$
Journal Wear	$\frac{1}{2}''$
Box Tolerance	$+\frac{1}{8}''$

This condition gives a minimum clearance between journal and box of $2\frac{7}{8}''$ and a maximum of $3^{31}\frac{1}{32}''$, or a difference of $1\frac{3}{32}''$. The importance of the resiliency of the pad over long service periods and ambient temperature conditions is readily apparent.

A considerable number of these pads have been developed. Figures 9, 10, 11 and 12 are typical examples.

These pads are then screened through the AAR Research Center and if found suitable are approved for field testing. The final evaluation is then made by field service tests. Some of the difficulties encountered with pad type lubricators are:

1. Failure to feed oil to journals at low temperatures.

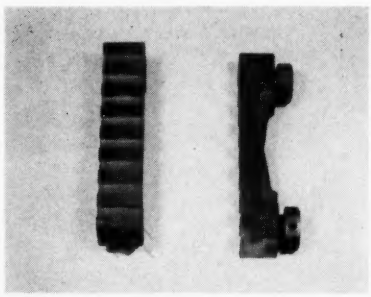


Fig. 14. Magnus R-S Journal Stop.

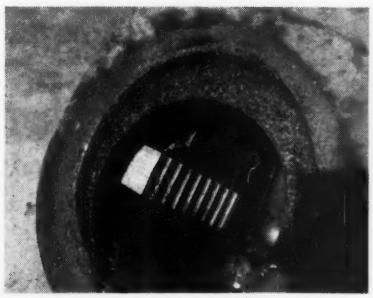


Fig. 15. Journal Stop in Position.

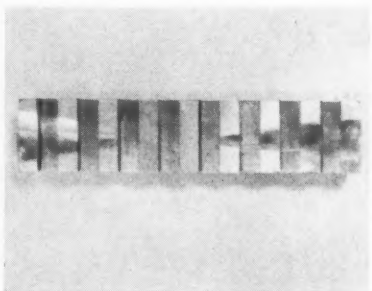


Fig. 16. End Wear of Journal Stop.

2. Deterioration of materials causing pads to collapse and settle away from journal.
3. Pad shifting in boxes, necessitating application of retaining devices to hold pads in place.
4. Accumulation of water in pads restricting the flow of oil.
5. Loss of oil from boxes due to lateral and vertical journal movement, necessitating consideration of improved devices to seal dust guard opening.

SOME QUESTIONS

Past performance has clearly developed that hot boxes which are lubrication failures are initiated by other factors than the lubricating medium. The introduction of new types of lubricating devices will bring certain difficulties which should be recognized and corrected. Some of these are the redesign of journal bearing and wedge to give extended service life in order to obtain maximum serviceability as a result of improved lubricating medium. Journal box lids must be tight fitting to provide maximum protection to the front of the box. This means maintenance of journal box hinge lugs. Improved retaining devices, either portable or permanently cast in journal boxes, to hold pads in proper position will be required. Journal stops and similar devices may have to be introduced to eliminate bearing displacement as a result of impact (Figure 13) — this again to insure maximum journal bearing life and to afford protection to dust guard. Dust guard seals must be improved or developed to insure protection against contamination and loss of lubricant through rear of journal box.

In addition, it will be necessary to set up standard procedures to overhaul lubricating devices at time of repack. Length of repack period must be realistically established. Reclamation possibilities have to be determined. Appropriate charges must be worked out. Inspection forces must be re-educated as to the peculiarities of the different pads and where the weak points are. These are some of the problems facing us. There will be others.

SOME ANSWERS

As indicated before, one of the major problems is the axle and bearing displacement under impact. This is illustrated by Figure 13. Closely allied with this is the shifting of the packing medium. This shifting can occur with either the waste or lubricating device. One answer proposed, and actually in service, is the "journal stop", shown in Figure 14. Figure 15 shows the journal stop in position, which gives $\frac{3}{32}$" clearance between stop and journal. By limiting the lateral movement of the journal they tend to keep the bearing and wedge in place. Also note the protection given to the dust guard. Without stops these are usually found broken. About two years of limited experience with these devices show that they perform satisfactorily, although some wear is experienced at the ends. Figure 16 shows this condition. The use of an aluminum alloy composition in place of the bronze is the latest development.

Also, as mentioned before, because of poor sealing at the rear of the box, foreign matter, such as dirt, snow, rain and other undesirable contaminants find their way into the journal box where they contaminate the oil. Some advances have been made toward developing better seals. Following are some examples. Figure 17 shows the standard AAR type. Figure 18 shows a plastic type. Figures 19, 20 and 21 show types that depend upon a neoprene rubber sealing ring that is either spring loaded or pleated to provide sealing at the dust guard seat. Figure 22 shows a seal developed by the B&O Research Department. It is constructed of foamed plastic with a synthetic rubber inner ring. Some advantages of this seal are that it is resilient enough to allow for the movement of the axle without breaking. It will not deteriorate over the temperature ranges involved, and it allows for a $\frac{1}{2}$" reduction in axle size. Limited service performance of this seal is encouraging. The AAR has approved its use by the B&O Railroad and also authorized test application to 10,000 cars on other roads.

JOURNAL RESISTANCE

Many people appear to be under the impression that the bearing friction of railroad cars equipped with roller bearings is significantly less than those equipped with the AAR standard bearing. In fact, when discussing roller bearings, the standard bearing is often referred to as the "friction bearing". Field tests conducted in 1935 on the Pennsylvania Railroad with oil lubricated roller and standard bearings indicated that the greatest journal resistance advantage of roller over standard bearings occurs at starting and low speeds. Under average conditions and with oil lubrication, the roller bearing resistance is very much lower up to speeds of 5 mph. This is a very significant advantage for the roller bearing where steam locomotives are used because steam locomotives can haul more than they can start. However, above speeds of 5 mph there is no significant difference in the resistance of the two types of bearings. However, diesel locomotives can start more than they can haul. Therefore, with diesels the difference in friction at starting and low speed loses its significance.

TRAIN RESISTANCE

Journal resistance is not the only resistance which must be overcome to move freight cars. Let us examine the

Fig. 17. Standard AAR Dust Guard.

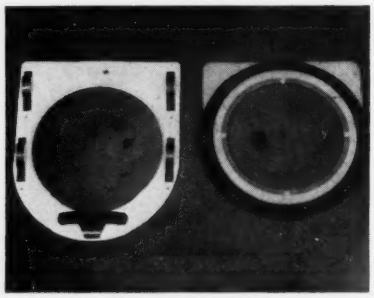


Fig. 18. Hennessy Dust Guard.

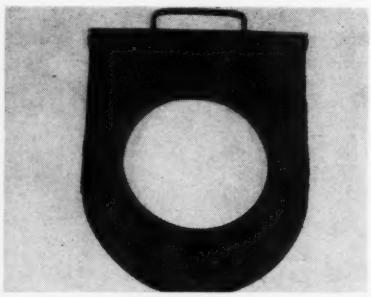


Fig. 19. Foss Dust Guard.

other factors involved. The Davis formula for freight car train resistance, which has received wide recognition in this country, is as follows:

$$R = 1.3 + \frac{29}{w} + 0.045V + \frac{0.0005\,AV^2}{wn}$$

Where:

R = The train resistance in pounds per ton
w = The average weight per axle in tons
V = The speed in miles per hour
n = The number of axles per car
A = The area in square feet of the cross-section of car body

The quantity $1.3 + \frac{29}{w}$ is the journal resistance and remains constant throughout the speed range. The quantity $0.045V$ is the wheel flange resistance for freight car trucks and increases as the speed increases. The quantity $\frac{0.0005\,AV^2}{wn}$ represents the air resistance and increases in proportion to the square of the speed.

Let us consider the hypothetical case of an eight wheel car weighing 50 tons going 50 mph. The resistances are:

Journal Resistance .....3.62 pounds per ton
Wheel Flange Resistance....2.25 pounds per ton
Air Resistance .....2.25 pounds per ton

From this it is evident that approximately 45% of the resistance is journal resistance. Therefore, if the journal resistance was reduced 5% the reduction in overall train resistance would be slightly over 2%. These figures are for level tangent track. Resistance on curves increases 0.8 pounds per ton per degree of curvature and 20 pounds per ton for each percent of ascending grade. Using the 50 ton car at 50 mph on a 0.5% grade with a 2° curve, the train resistance becomes 19.72 pounds per ton of which the journal resistance is about 18% of the total. As grades and curves increase, the journal resistance becomes a smaller percentage of the total and any reduction in journal resistance becomes relatively insignificant in its effect on train tonnage and speed of movement.

OIL LUBRICATION

Oil lubricated roller bearings have proved highly efficient on passenger cars and locomotives. Oil is used satisfactorily because it is not a problem to check and replenish it and this type of equipment is not subjected to being overturned on dumping machines where the oil may be lost from the boxes. In normal service oil is also likely to be lost from the box due to imperfect sealing. On passenger cars oil lubricated roller bearings are required to be inspected and oil added, if necessary, every 30 days. Locomotive roller bearings are inspected as frequently. These frequent inspections are costly and could not be tolerated on the large number of freight cars if equipped with roller bearings. So we turn to grease lubricated bearings.

GREASE LUBRICATION

Grease lubricated roller bearing journal starting and running resistances are generally higher than with oil lubrication. This was shown in tests conducted by the AAR laboratories from 1946 to 1949. This was indicated again in 1956 when testing a hot box detecting device based on a thermal pickup mounted near the tracks. It was difficult for the instrument to differentiate between overheated plain bearings and grease lubricated roller bearings. Grease is used as a lubricant for roller bearings because of its ability to remain in the journal boxes over extended periods. Grease lubricated passenger car roller bearings require attention every 90 days. At present, freight car boxes require relubrication at one year intervals and it is expected that this can be increased to three years. For these reasons grease has become the standard roller bearing lubricant even though from a journal resistance standpoint it is less desirable than oil.

COST

Probably the largest single factor that will delay the application of roller bearings is the high initial cost. To equip the 1,971,000 freight cars now in existence at an average cost of $700.00 per car would mean an initial outlay of 1.38 billion dollars. A staggering sum considering that 2.47 billion dollars was required to purchase the 24,700 diesel units in service on the American railroads in 1955. However, the railroads should continue their studies on cars already equipped to determine the relative costs of servicing and delays with both types of bearings. Bearing manufacturers should concentrate on improved production techniques to reduce the cost of roller bearings to an economically feasible level.

CONCLUSION

It is gratifying to see that there is continuing, vigorous, positive action being taken to improve railroad freight car performance. Very significant improvements in service to customers have resulted. More improvements will continue to come.

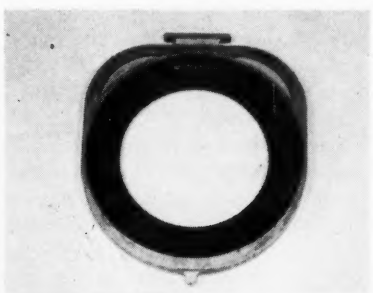


Fig. 20. Johns Manville Dust Guard.

Fig. 21. Empire Dust Guard.

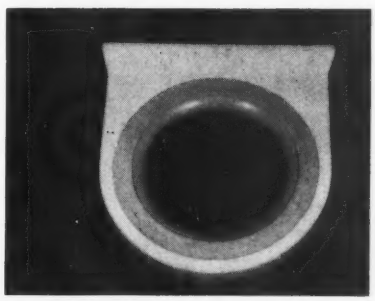


Fig. 22. B & O Guard Seal.

Electron Diffraction in Lubrication Research

Douglas Godfrey, California Research Corporation, Richmond, Calif.

Electron diffraction is the most useful technique in revealing information on the nature of a surface. This paper reviews the contributions of electron diffraction in the field of lubrication research and points out the important aspects of the technique as it is applied to this field. The theory of diffraction by crystals, specimen preparation and pattern interpretation are covered. Examples of diffraction patterns from friction surfaces are presented.

Knowledge of the nature of surfaces is increasing in importance in lubrication studies. The action that occurs between sliding or rolling surfaces may be only partly related to the bulk properties of the bearing material or the lubricant. Further progress will depend on a greater knowledge of surface properties.

Electron diffraction is the most useful technique in revealing information on the nature of a surface. The purpose of this paper is to point out important aspects of electron diffraction technique and to review its contributions in the field of lubrication research. It is particularly adapted to lubrication studies because electrons do not penetrate beyond about a hundred atom layers of material, which is the zone where sliding occurs and lubricating films are formed. X-rays penetrate deeply into matter and do not normally detect thin films; whereas, electrons lack penetrating power because they are scattered by the intense electric field of atoms. If the film is crystalline, electron diffraction can be used to determine crystal structure and orientation, to give an indication of size and number of crystals, and to give, in some cases, chemical composition of the film, even if two or three phases are present.

Electron diffraction has served investigators of lubricating phenomena, and its use is increasing. Early work was done by French[1] who in 1932 studied the polishing of metal surfaces. A great deal of research on the Bielby layer followed French's work. These investigations were reported in detail in 1953 by Pinsker[2] who concluded that it is not yet fully established whether the diffuse halos pattern obtained from a polished surface is a result of an amorphous or a microcrystalline phase. Electron diffraction has furthered an understanding of the mechanism of run-in and surface changes caused by sliding. This technique has also revealed depth of cold worked zones, orientation, amorphousness, and oxides, nitrides, and carbides on metal surfaces. Wulff's paper,[3] showing metallurgical transformations in depth, is representative of this type of investigation.

A major effort has also been made toward the detection of order in organic molecules adsorbed on solids. Brill[4] has reviewed the literature and indicated that electron diffraction examination has shown the preferred orientation and close packing of long chain fatty acids on a metal surface.

Electron diffraction is very useful in the study of solid film lubricants, particularly in revealing the chemical composition and orientation of natural films and deposited powders. The research of Simard, Russell, and Nelson[5] is an outstanding example of successful use of electron diffraction to reveal chemical composition of compounds associated with extreme pressure lubrication. At the Lewis Laboratory of the National Advisory Committee for Aeronautics, electron diffraction has been used to study friction and wear phenomena. Identification was made of films formed on steel when heated with chemical compounds of the type used as lubricant additives[6]. Preformed films on steel were identified prior to determination of friction and wear characteristics.[7] Further, electron diffraction was successful in identifying very small quantities of debris produced in fretting experiments.[8]

The physical nature and chemical composition of metal corrosion products is important in understanding lubrication phenomena. Phelps, Gulbransen, and Hickman's work,[9] for example, has shown the important variables in the formation of oxide films on iron, steel, and other bearing metals.

THE THEORY OF ELECTRON DIFFRACTION

The wave length of a stream of electrons depends upon the accelerating voltage. A simplified equation to express wave length in terms of accelerating voltage is $\gamma = \frac{12.225}{\sqrt{V}}$, where λ is wave length in angstroms and V is volts. Thus, an accelerating voltage of 40,000 volts gives a wave length of 0.06Å.

A stream of electrons impinging upon atoms is scattered as expanding spherical waves. If the atoms have a geometric order in space, as in a crystal, the scattered waves reinforce in certain directions and interfere in other directions; that is, diffraction occurs.

Diffraction is expressed by Bragg's law, which is

$n\lambda = 2d \sin\theta$ where,

d = interplanar distance in angstroms

θ = angle of reflection between the crystalline plane and the beam

λ = wave length of the electrons in angstroms

n = a whole number

This equation states that scattered waves from a family of planes will reinforce each other only when the difference in the distances they travel is an integral number of wave lengths. This condition is represented schematically in Figure 1. In order for the beam I_r, reflected from plane AA, to be in phase with the beam II_r, reflected from plane A′A′, the difference in their path length P′P + PP″ or $2(d \sin\theta)$ must be an integral number of

wave lengths. Thus, if Bragg's law is satisfied, one set of planes in one crystal will "reflect" the incident beam, and it will produce a spot on a photographic plate. If there are a number of small crystals randomly oriented in the path of the beam, a cone of electrons will be produced from the same set of planes in the many crystals. This effect produces a circle of spots on a photographic plate. The diameter of this circle is directly related to the distance between the planes. Other sets of planes in the crystalline material will produce other circles, forming a concentric ring pattern which is characteristic of the crystalline structure of the particular material.

EXPERIMENTAL TECHNIQUES

Apparatus and Procedure

The components of any electron diffraction apparatus are shown schematically in Figure 2. A photograph of commercially available equipment is shown in Figure 3. A beam of electrons is accelerated through an anode aperture and focused on a photographic plate by means of a magnetic coil. Collimating apertures are placed in the path of the beam to reduce scattering and to limit the diameter of the beam. Provision is made for manipulating or moving specimens into the beam path. In some equipment a magnetic coil is placed between the specimen and the photographic plate to reduce the specimen-to-plate distance. A grease and oil-free system and a vacuum of 10^{3-} to 10^{4-} mm of mercury are essential for high quality patterns.

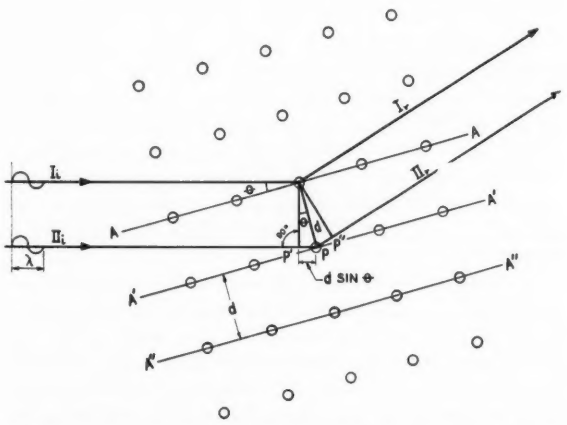


Figure 1. Diffraction in a crystal (Bragg's Law — $\eta \lambda = 2d \sin \theta$).

Specimens may be examined by the transmission method or the grazing incidence method, as shown in Figure 4. The material from which the diffraction pattern is to be obtained must be placed in the path of the beam in each case so that the electrons can pass through it. Electrons are said to be transmitted when they enter and leave the sample through different surfaces, and the beam is approximately perpendicular to these surfaces. Electrons are said to be reflected when they enter and leave the sample through the same surface, and the beam is at a grazing incidence to the surface. In lubrication studies, both methods are used, but since the unknown phase almost always exists on the surface of metals, the arrangement of grazing incidence is of greater importance. Normally, surfaces are rough and electrons are transmitted through projections, but sometimes additional roughening will improve a pattern. In lubrication studies, the reflection method is limited to specimens with very smooth surfaces, such as cleaned mica, electropolished single crystals, or adsorbed organic molecules on smooth surfaces. The size of a specimen is limited only by the space available to mount and manipulate it in the apparatus. Some equipment has very small specimen chambers which take only specially made specimens; others have large chambers which take parts of machines or large panels. A specimen may be any shape as long as the diffracted electrons are not obstructed by, or trapped in, a concavity.

Specimens, such as loose powders, wear fragments, evaporated films, and films detached from metal surfaces, may be examined by the transmission method. In this case, the unknown is deposited on a fine mesh screen. The deposit must be thin enough to permit transmission of the electrons (usually determined by trial and error). Supporting films of electron transparent material are useful for holding very fine powders. The techniques used to make supporting films for electron microscopy are suitable for electron diffraction.

Specimen Preparation

The basic requirement in specimen preparation is to expose the unknown phase for transmission of the electron beam. Carelessly prepared specimens and shortened procedures rarely yield usable patterns. Meticulous work and cleanliness are required for electron diffraction. In studying inorganic surface films, oil and greases are removed by gentle scrubbing in the presence of a pure low boiling solvent. The solvent leaves a residue on evaporation which can be tolerated so long as it does not mask

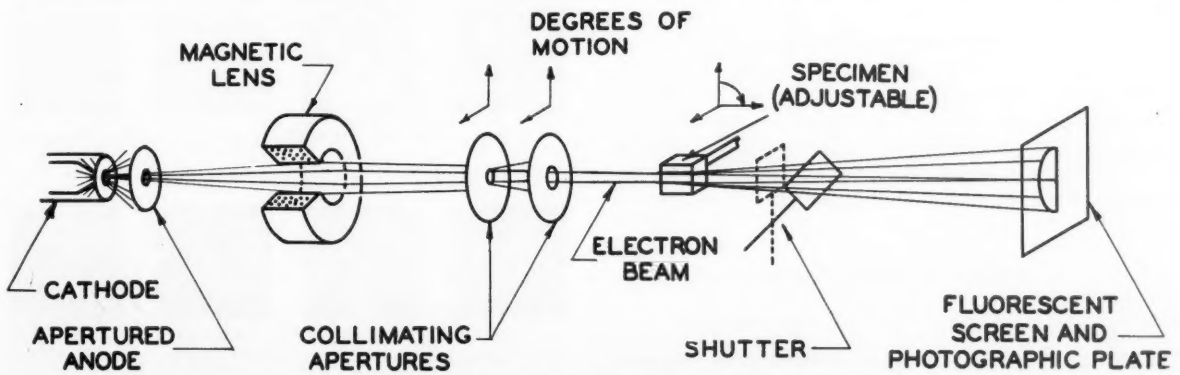


Figure 2. Elements of electron diffraction apparatus.

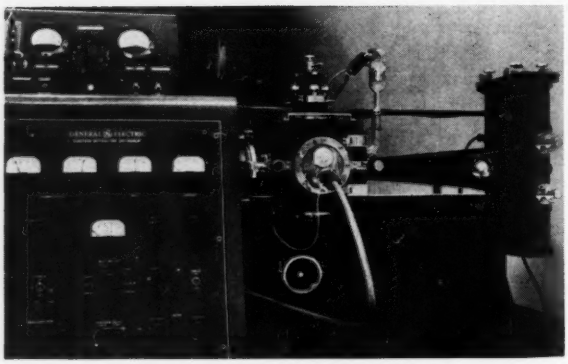


Figure 3. Electron diffraction equipment.

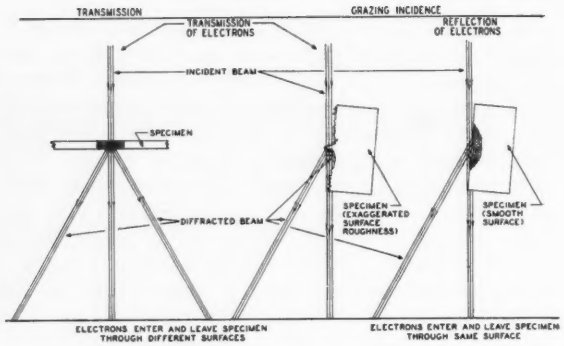


Figure 4. Electron diffraction methods.

the film. In studying organic films on metal surfaces, such as soap formation, treatment and solvents must be carefully chosen so that changes in adsorption and orientation are known.

Examples of specimen preparation for a number of important materials are:

1. **Iron and Steel Surfaces** — The alpha-Fe of iron and steel can be exposed by abrading the specimen on 2/0 metallographic paper under chemically pure benzene. This technique minimizes oxide and rust formation and produces an alpha-Fe pattern like the one shown in Figure 5a.

2. **Oxide Films on Iron and Steel** — A pattern of rust, gamma-(FeOOH), in Figure 5b is important because of the very common occurrence of this material. It is readily formed by exposing clean steel to warm, humid air.

A film with a surface of ferric oxide, alpha-Fe_2O_3, Figure 5c, is easily formed by heating clean steel in air until interference colors appear. Time, temperature, and age affect the nature of this film.

A film of ferrosoferric oxide, Fe_3O_4, may be formed by heating clean steel in oxygen at a pressure below 1×10^{-3} mm of Hg. The pattern is shown in Figure 5d and is representative of spinel-like structure. A similar pattern is obtained for gamma-Fe_2O_3; these two compounds are difficult to distinguish by diffraction methods.

3. **Metal Sulfides and Chlorides** — Films of these compounds on iron and steel can be formed by heating the metal in atmospheres of H_2S and HCl, respectively, under special conditions[7]. Patterns of FeS and $FeCl_2$ are important standards in the studies of extreme pressure lubrication. Patterns of FeS and CuCl are shown in Figures 5e and 5f.

4. **Organic Monolayers** — Monolayers of long chain hydrocarbons adsorbed on metal surfaces can be detected by electron diffraction. A monolayer of stearic acid, for example, may be deposited on polished copper by the Langmuir-Blodgett technique.[10] The electrons respond to the preferred orientation of these molecules and produce a diffraction pattern of parallel streaks similar to one shown in Figure 5g.

PATTERN INTERPRETATION

Crystallinity

Electron diffraction patterns reveal the degree of crystallinity of material. A change from high order crystallinity to amorphousness is represented schematically in Figure 6. At one extreme is a pattern composed of a very few spots from a single, well developed crystal. If the spots tend to form rings, the diffracting material is composed of a number of large crystals. If the spots which comprise the ring are small or not visible to the unaided eye, the diffracting material is composed of fine crystals. Very broad and rather weak intensity rings, which are difficult to measure accurately, indicate the presence of a very fine crystalline material. At the other extreme are the diffuse halos which are produced by material with poor or no crystallinity and approaching amorphousness. These halos are common in lubrication research and are given by polished and worn surfaces, contaminated specimens, and lacquer films.

Concentric Ring Patterns

Of greatest importance in lubrication studies is the concentric ring pattern which premits determination of the chemical composition of crystalline material. Figures 5a through 5f are representative of the well defined concentric rings pattern. Each material produces a characteristic pattern which may be thought of as an identifying "fingerprint." The necessary steps to determine chemical composition from the pattern of an unknown are as follows:

1. A pattern of a compound with well established crystallographic data is obtained with the electron diffraction instrument at the same settings as those used for the unknown pattern. Magnesium oxide, zinc oxide, and gold are commonly used. The radii of the rings of these standards are measured, and each radius is multiplied by its

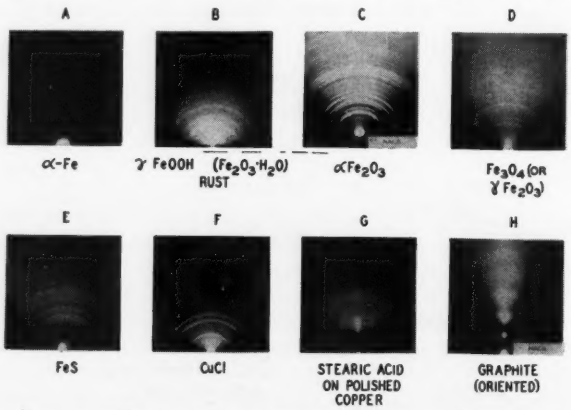


Figure 5. Diffraction patterns of materials common in lubrication.

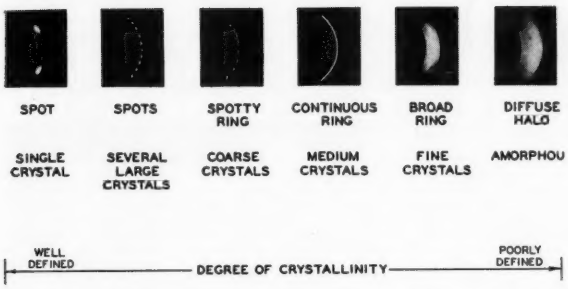


Figure 6. Effect of degree of crystallinity on electron diffraction patterns.

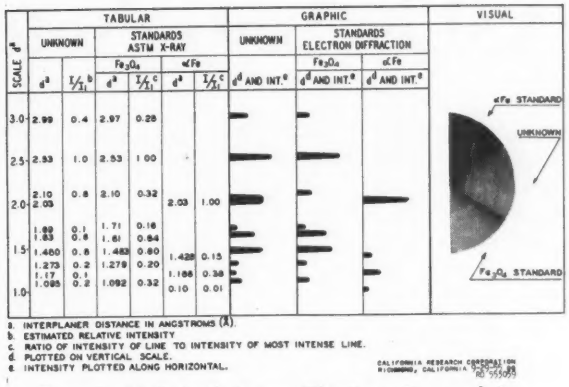


Figure 7. Methods of electron diffraction pattern analysis.

d value, published in the ASTM X-Ray Diffraction Card Index. The weighted average of these products is the Instrument Constant for the unknown and also for other patterns which were taken at the same instrument setting.

2. The radius of each ring on the unknown pattern is measured. (If the ring is broad, the inside and outside dimensions and the radii of maximum intensity are measured.) Each of these values is then divided into the Instrument Constant to obtain a list of *d* values for the unknown. Then the relative intensity of each ring is measured or estimated. If intensities are estimated visually, the value 1.00 is assigned to the most intense ring and fractional values for less intense rings.

3. This list of interplaner distances or *d* values and their relative intensities are then used in searching the ASTM X-Ray Diffraction Card Index and other reference files for a matching pattern. If the three most intense rings can be matched to the standard and their intensities are of the right magnitude, then positive identification is possible. The identification is confirmed by making visual comparison with electron diffraction patterns that the investigator prepares from pure compounds. Such electron diffraction standard patterns permit better matching of intensities, inasmuch as the intensities from X-ray and electron diffraction are slightly different.

The identification is often aided by plotting the data on graphs as shown in Figure 7. This plotting helps to reveal two-phase systems when some intensities are too high because of the superposition of two patterns with coinciding rings. Coincident rings from two materials increase the photographic plate exposure, thus giving an apparent increased intensity to a ring. Figure 7 shows three methods of examining data. The figure shows that, with a mixture of Fe_3O_4 and alpha-Fe, the patterns are superimposed and give the broadest and the most intense ring at a *d* value ranging from 2.10-2.03Å. This ring is recognized as a combination of the 2.10Å ring from Fe_3O_4 and the 2.03Å ring from alpha-Fe.

Arc Patterns

Of significance in lubrication research is the occurrence of "preferred orientation," which is a condition of crystals or long chain molecules with their axes in ordered positions. Electron diffraction reveals preferred orientation by the production of arc patterns. An arc is a segment of a ring of a concentric ring pattern showing maximum and minimum intensities along its circumference. Preferred orientation often occurs with thin, inorganic films on metal surfaces. At the interface the films assume the crystalline structure of the worked metal. Finch[11] stated that this condition was desirable for solid film lubrication.

An extreme of preferred orientation is the pattern usually obtained with laminar or layered latticed compounds used as solid lubricants, such as graphite and molybdenum disulfide. An example of preferred orientation is given in Figure 5h which shows a series of spots normal to the edge of the specimen shadow, which is produced by repetition of the position of the (0001) plane of graphite with reference to the electron beam. Similarly, sliding of cast iron also causes a preferred orientation of occluded graphite onto the surface.

Acknowledgement

The author wishes to acknowledge the assistance of Dr. Robert E. Barieau of the Analytical and Physical Measurements Division of California Research Corporation and the cooperation of the National Advisory Committee for Aeronautics in supplying two of the diffraction patterns in Figure 5.

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Discussion on Page 612

ASLE News Notebook

The fourth annual joint ASLE-ASME lubrication conference, successfully concluded in Toronto on Oct. 9, witnessed the presentation of many excellent papers by members of both societies, centered around the subject of "Lubrication and Wear."

In addition, two reporter sessions conducted by Ernest Rabinowicz and H. A. Hartung gave session registrants and guests an opportunity to evaluate the papers presented at the I Mech E Conference on Lubrication and Wear held in London Oct. 1-3. Over 40 abstracts were presented by the two session chairmen, who also answered questions from the floor. In the opinion of many observers, hydrostatic lubrication was the subject most thoroughly examined at the London conference.

Active question and answer discussions formed an important part of the six major sessions, which included: "Recent Experiments in Wear"; "Boundary Lubrication"; "High Temperature Lubrication"; "Factors Affecting Contact Fatigue"; "Fluid Film Lubricated Bearings"; and "Recent Studies in Fluid Film Lubrication."

In spite of, or perhaps because of, the highly informative and technical nature of the conference, members and guests made full use of the opportunities offered to exchange problems and renew old acquaintances. A cocktail reception and dinner on the first evening of the conference was sparked by the appearance of the presidents of both societies.

Dinner was followed by brief addresses by J. O. McLean and W. R. Ryan, who summed up the spirit of international and inter-society cooperation in their short talks. Canadian vice-president T. A. Marshall, in delivering a welcoming address, also underlined the joint nature of the get-together. Members of both ASLE and ASME Canadian sections were on hand in force to welcome their American colleagues.

The majority opinion of members and their guests attending the conference agreed that a great deal of information was exchanged in the shortest possible time, both in the actual sessions and in informal meetings. In other words, a profitable and enjoyable time was had by all.

H. A. Hartung (left) and E. E. Bisson, vice-chairman and chairman of the Lubrication Conference Planning Committee, meet at the reception desk to discuss some aspects of conference business.

William R. Ryan, ASME, President, addresses members and guests assembled at dinner. From left to right at the president's table: E. E. Bisson, Mr. Ryan, T. A. Marshall, H. A. Hartung, J. O. McLean, C. I. R. McDougall, D. F. Quan.

Left: C. I. R. McDougall, T. A. Marshall, and Bill Mann, Canadian ASLE members, get together at cocktail party. Right: W. R. Ryan and J. O. McLean, ASLE president, sit down for a quiet talk after dinner.

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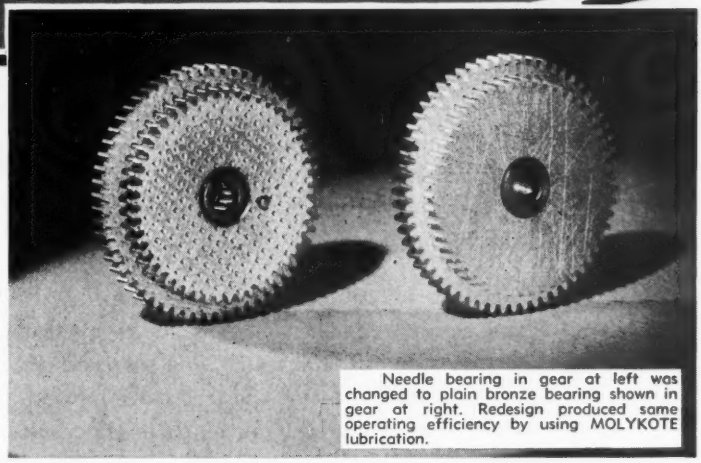

Needle bearing in gear at left was changed to plain bronze bearing shown in gear at right. Redesign produced same operating efficiency by using MOLYKOTE lubrication.

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Eight experts in the field of industrial dermatitis assemble for the first time their experience and investigations in an ASLE-sponsored effort to curb these costly diseases. More than $100 million dollars in manhours are lost to American industry annually as a direct result of one or more forms of industrial dermatitis.

Five medical practitioners, a chemist, and lubrication and resident engineers examine the use and handling of cutting oils, lubricants, and solvents; and discuss protective measures in terms of ointments, housekeeping, and prevention of bacterial decomposition. While no blanket solution is agreed upon, one of the many measures outlined here may prove a solution to your specific plant problem. An informative panel discussion among all participants concludes the booklet.

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A newly developed tapered orifice valve offers a unique concept of flow control. By moving a plug with a tapered slot into and out of a circular opening, the flow of fluid or gas is controlled by the area of the tapered slot at the head of the opening. A circular sealing ring eliminates by-pass. Reportedly replacing the needle valve in nearly all applications, this valve will pass foreign particles up to 20 times larger than comparable needle valves. Principal advantages include: highly accurate, infinitely variable control; non-clogging; non-freezing; abrasion-resistance, and excellent coefficient of flow at all settings with very low turbulence. Thoroughly field-tested, the tapered orifice valve is available in many sizes, pressure ranges, and connections. Additional information will be furnished on request by General-American Valve Co., P. O. Box 444, Corona Del Mar, Calif.

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A water soluble lubricant and coolant, representing a departure from the principle of lubricant-cooling by extreme pressure with petroleum emulsion oils, has been developed. The coolant is said to make use of a natural adhesiveness in the new fluid which results from a chemically generated electrostatic charge. This reportedly prevents the cooling fluid from building up on the metal to more than one molecule thickness. Extensive shop use and laboratory tests indicate that the new coolant is especially effective in working titanium. Present users report better finishes, increased speeds and feeds, and improved tool life. For further details on "Crystal Cool", write to Clinton Chemical Co., 1619 20th St., Santa Monica, Calif.

COMPOUND FLOATS DIRT AWAY

A scientifically-developed safety cleaning compound for industrial use, is diluted with water for cleaning production machinery in machine shops and manufacturing plants. This compound reportedly makes it possible to eliminate use of flammable or toxic solvents for washing down machine tools and other equipment. Non-flammable, the compound neither gives off objectionable odors nor burns the skin, thus making it feasible to apply by pressure spray. Unlike solvents that merely thin out accumulated oil and dirt and spread them over a larger surface, the wetting agents in this new compound are said to penetrate through layers of dirt, enveloping each soil particle with a surface active agent. When the equipment is wiped with a dampened rag, the dirt is floated away from the surface, leaving it clean and, if desired, ready for painting. The Daniel Co. of Lowell, Mass. can be contacted for further information on "Danite."

SECTION NEWS....

Pittsburgh—First meeting of 1957-58 season saw 59 members and guests present at a talk by William Hollibaugh, evaluation chief at Sun Oil. Mr. Hollibaugh, reviewing the history of crankcase oils, cited the trend to higher temperatures and strains in modern high-compression engines as a factor in the development of special additives. Driving habits have changed too, he added, and increased stop-start and short distance driving create more engine deposits peculiar to low temperature operation, as well as rust. Ordinary hi-temp detergents simply don't work under these conditions, concluded Mr. Hollibaugh . . . George L. Sumner, Jr. presented the section with a gavel awarded his father, a past ASLE president, by National Headquarters . . . C. T. Charlton, transferred to Chicago by his company, handed over treasurer's duties to James Read, financial committee chairman. Executive Committee election results: 1957-58 officers include A. D. Binz, chairman; A. J. DeArdo, vice-chairman; O. B. Rosstead, Jr., secretary; James Read, treasurer.

Twin Cities—G. T. Coker, Jr., Shell Oil Co. petroleum technologist, addressed a meeting Sept. 26 at the Hotel Dyckman. His subject: "Use of Emulsions as Power Transmission Fluids"—a topic of current interest to many ASLE members . . .

Syracuse—At regular monthly meeting, cocktail hour and buffet dinner was followed by a talk on "Practical Application of Greases and Synthetic Lubricants" delivered by George Kellis, chief industrial products engineer of Sinclair Oil Co.'s home office . . .

Kingsport—In line with a suggestion from the National Office, calling for "reporters" for *LUBRICATION ENGINEERING*, P. J. Galbreath of the Tennessee Eastman Co. has been appointed . . . he will serve as an area representative for the journal, reporting on local developments, problems, and topics of national importance in the field of lubrication. One of his major functions in this newly-created section responsibility will be to channel to LE editors noteworthy papers dealing with lubrication practice given at section meetings. All sections have been requested to nominate a member for this new responsibility, vital in the planned extension of LE's coverage of geographical and industry areas.

New York—J. J. O'Connor, managing editor of "Power" magazine, moderated a panel discussion on "Everyday Problems in Lubrication", with experts Anthony Hepp, C. G. Hollister, R. J. Ronan, and R. L. May . . . actual service problems in specific plants were dissected . . . L. E. Hoyer spoke during dinner on "Can Lubrication be Re-Established in a Hot Bearing?"

Intermountain—Newly-formed section held its first social hour and dinner, opened by chairman Dudley Thomas . . . Jim Kyle reports membership now 34, and hopes to double that figure by the anniversary meeting . . . 31 members and guests attended the fifth meeting, and heard Douglas Godfrey of California Research speak on "Fretting Corrosion", with slides and movies . . .

Boston—A dinner meeting at the M.I.T. Faculty Club set the scene for Executive Committee discussion of publicity and education . . . Cedric Valentine named new publicity chairman . . . Local education awards suggested, with emphasis on soliciting papers dealing with ingenious solutions to lubrication problems from local industries. Best paper would receive award, increasing recognition of society and fostering practical and research approaches in the field . . . Heard at Oct. 21 meeting—Frank D. Archibald on "Soap Film Analogies to Lubricants and Viscous Flow Problems." Future speakers: T. W. Bakewell, "Ball Bearing Care"; George Gydesen, "Application of Mist Lubrication"; E. J. Krabacher, "Metal Working; John Owens, "Die Lubricants" . . .

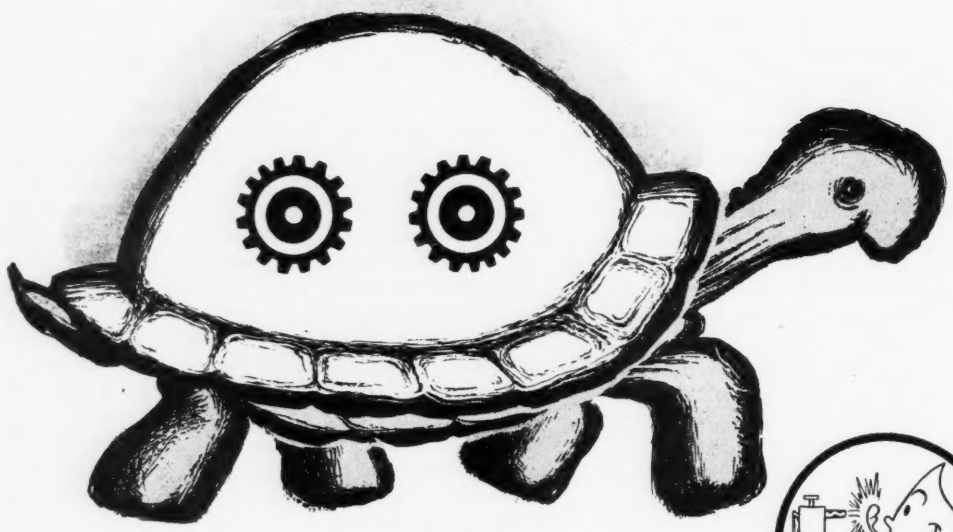
Ontario—Over 80 members and guests attended a panel discussion (Sept. 10) on metal cutting . . . questions to panel members Alex Ironsides, John Holden, W. H. Mann, and A. McKinney Rice submitted from the floor covered cutting oil chemistry, what the user should expect from the lubricant, typical shop practice in cutting oil usage, and cutting oil evaluation . . . panel members represented a healthy cross-section of industry, and gave the points of view of their respective fields . . . Future meeting topics: "Silicone Lubricants", "Lubrication of Nuclear Power Auxiliaries", "Recent Developments in Oil Dehydration" . . . of special interest should be a talk on Dec. 10 by R. O. Standing, senior maintenance engineer at Ontario Hydro who will give his "Reminiscences of a Mechanical Maintenance Engineer" . . .

Montreal—"Lubrication Trends and Preventive Automobile Maintenance" was the topic on Oct. 2, discussed by Gordon Ritz, supervisor of technical training, Chrysler Corp. of Canada . . . Future meeting topics include "Vacuum Dehydration of Oils", "Lubrication and Preventive Maintenance in the Steel Industry" . . .

Chicago—"Bring a Guest Nite" (Oct. 17) offered free three month subscriptions to LE to every guest . . . members had added incentive of a door prize . . . Heavily attended meeting heard Bruce Dunham, Sun Oil technical consultant speak on "Air Compressor Lubrication" . . . Scheduled for Jan. 20: Ladies Night, with a talk on "How Women Influence Chemical Progress" (mightily, we'd say) by D. R. Mabon of Du Pont . . .

Duluth-Iron Range—Texas Co.'s Harold Grams gave a well received talk on "Fundamental Characteristics of Petroleum Products" at Sept. 25 meeting . . . Nineteen members and guests were present . . .

Los Angeles—At a joint dinner meeting (with the American Institute of Plant Engineers, Oct. 9) ASLE members and guests heard E. J. Gesdorf, senior application engineer at Farval deliver some highly current remarks on "Modern Methods of Lubricant Application". Mr. Gesdorf traced the history of centralized lubrication, covering basic design principles, control components, etc. Mainly, he commented, independent standards agree on four targets: personnel safety, no downtime, extended machine life, and good housekeeping. With one addition—reduction in operating costs—Mr. Gesdorf summed up his discussion . . .



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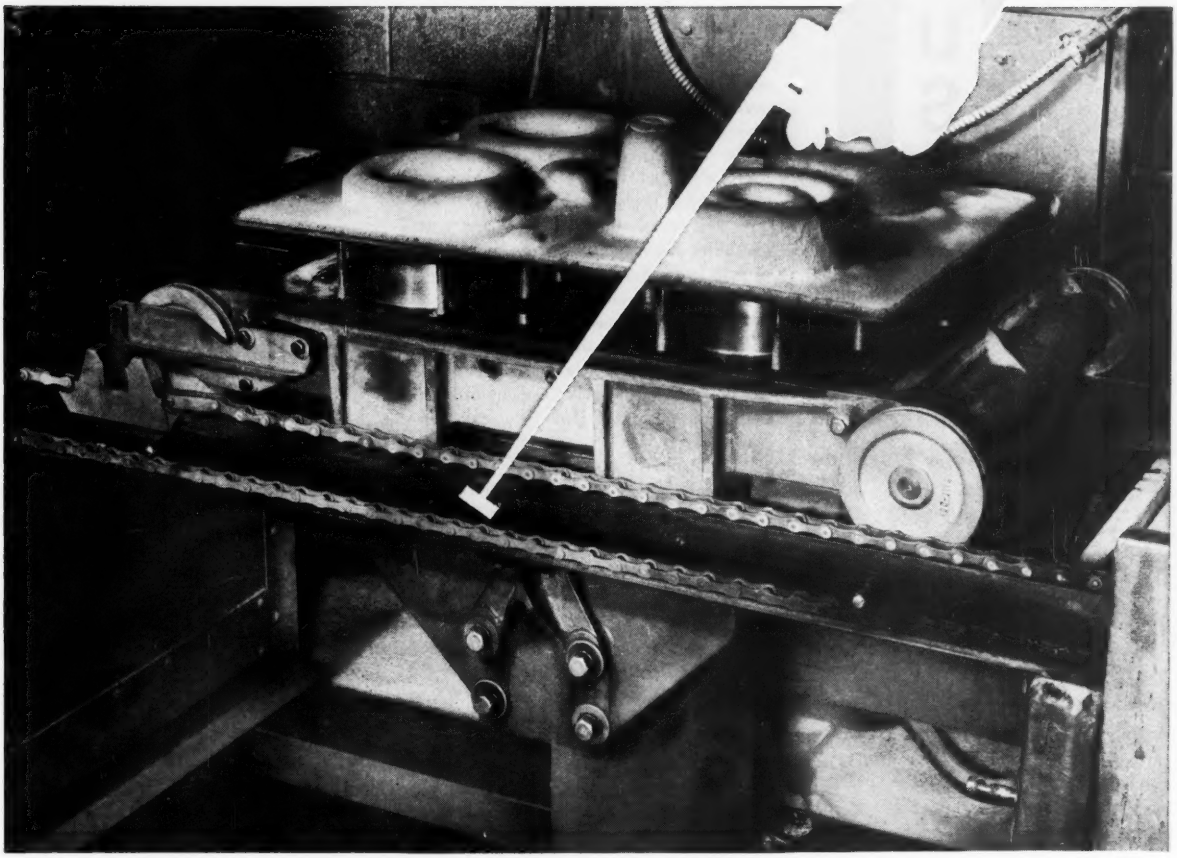

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FOUNDRIES' DIRECTORY

The Steel Founders' Society of America announces that its 1957-58 Directory of Steel Foundries in the United States, Canada, and Mexico is now available. This directory lists personnel, capacity, equipment, processes employed, use of product, and number of employees. It also features a geographical directory with much of the basic information coded for quick reference purposes. The 277 page directory is available at $15 per copy from the Steel Founders' Society of America, 606 Terminal Tower Bldg., Cleveland 13, Ohio.

ECONOMICS OF GLASSWARE

A 16-page, two color pamphlet which discusses the economics involved in the purchase of both lime and borosilicate glassware for laboratory use has been published. The booklet describes the applications for which borosilicate glassware must be used, but points out that substantial savings can be effected by using lime glass where it can be expected to perform satisfactorily. Lime and borosilicate glassware are compared in terms of thermal and chemical properties as well as in importance of accuracy in manufacture. Copies may be secured by writing Doerr Glass Co., Vineland, N. J.

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Personals

J. Philip Wettach has been named lubrication engineer for the Engineering and Construction Division of Dravo Corporation, Pittsburgh. Mr. Wettach, who

J. P. WETTACH

has been responsible for engineering on Dravo-DeLaval mill lubrication systems since he joined the company in 1955, succeeds **Kenneth D. Reed** who retired to make his residence in Florida. Prior to his employment by Dravo Mr. Wettach was employed by the DeLaval Separator Company in its mill lubrication department, which in 1955 was taken over by Dravo.

American Potash & Chemical Corporation has opened a new district office to be managed by Chester A. Lawton, at Columbus, Ohio, covering outlets in Ohio, eastern Indiana, southern Michigan and Kentucky.

ASLE member **William V. Bernsen** is now sales manager for Engine Life Products Corporation, El Monte, Calif., manufacturers and developers of lubrication and fuel-oil filtration.

Harry A. Robertson, Jr. has been assigned a new sales territory for the Garlock Packing Co., Palmyra, N. Y., in the central section of Ohio. He will work out of the Cleveland branch.

John A. Kriva has been named manager — manufacturing engineering for the Industrial Division of the Warner Electric Brake & Clutch Company, Beloit, Wisconsin.

The appointment of William J. Hawkins to the newly-created position of assistant service manager of the Alemite and Stewart-Warner Instrument Division of Stewart-Warner Corporation, has been announced.

PRICE LIST OF AEC REPORTS

A new free price list of Atomic Energy Commission unclassified research reports for sale by the Office of Technical Services, U. S. Department of Commerce, is now available from OTS on request. This cumulative listing of the more than 4,500 AEC reports in the OTS collection includes new documents acquired since December 31, 1956. To obtain the new list, request AEC Research Reports Price List No. 28 from OTS, U. S. Department of Commerce, Washington 25, D. C. Price lists are issued semi-annually, and the next list will be available in February 1958. OTS also publishes *U. S. Government Research Reports.*

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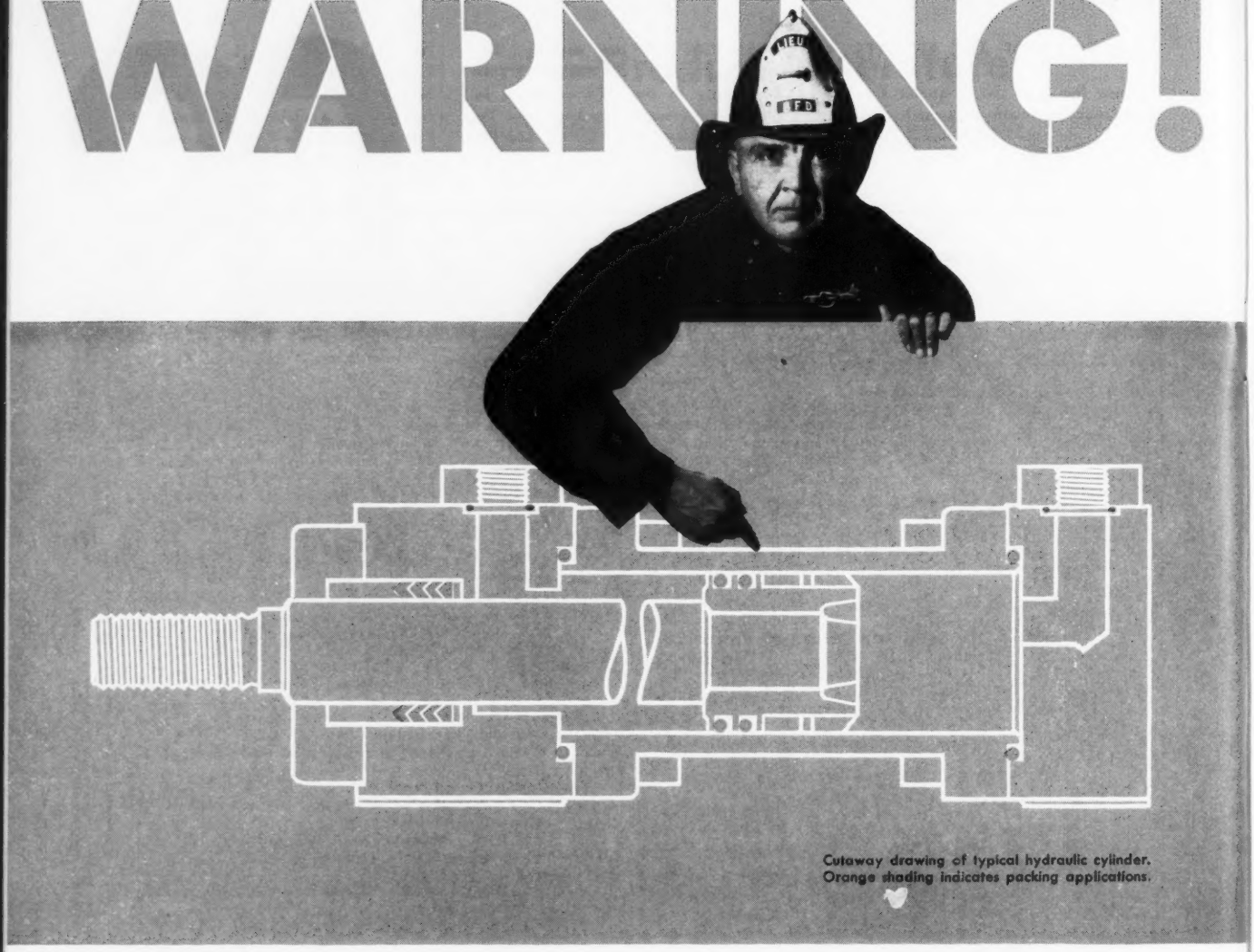

Cutaway drawing of typical hydraulic cylinder. Orange shading indicates packing applications.

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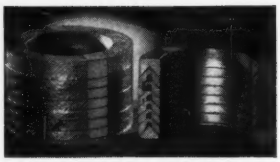

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Patent Abstracts

Mineral Lubricating Oil Additive, Patent No. 2,781,318 (E. B. Cyphers, assignor to Esso Research & Engineering Co.) A lubricant composition consisting essentially of a mineral oil and in the range of about 0.2 to 5.0% by weight of a compound.

Lubricating Compositions, Patent No. 2,781,319 (E. R. Barnum and L. E. Lorenson, assignors to Shell Development Co.) An improved mineral lubricating oil composition comprising a major amount of mineral lubricating oil and a minor amount, sufficient to depress the pour point of the oil and to improve its viscosity index, of a reaction product obtained by treating (1) a hydrolyzed copolymer of an α-hydrocarbon olefin of from 8 to 40 carbon atoms and a vinyl ester of a lower fatty acid of up to 5 carbon atoms with (2) an organic isocyanate, said final reaction product having a plurality of hydroxyl and carbamate radicals and the ratio of the number of polar groups to the non-polar groups per molecule varying from 1:10 to 5:1 respectively.

Grease Compositions, Patent No. 2,782,165 (W. H. Peterson and A. A. Bondi, assignors to Shell Development Co.) The method of preparing a grease composition which comprises extracting a grease comprising essentially a mineral lubricating oil and a soap of high molecular weight carboxylic acid, with a normally liquid solvent for said oil to remove substantially all of the mineral lubricating oil from said grease, displacing said normally liquid solvent with a liquefied normally gaseous second solvent, heating said soap and second solvent above the critical temperature of the solvent while maintaining the solvent in a liquid state, evaporating the solvent from said soap above the critical temperature thereof, whereby a soap aerogel is formed, and dispersing said aerogel in a second mineral lubricating oil, whereby a second grease composition is formed.

Ester Base Lubricating Greases, Patent No. 2,782,166 (J. J. Kolfenbach, A. J. Morway and P. V. Smith, Jr., assignors to Esso Research & Engineering Co.) A lubricating grease consisting essentially of lubricating oil thickened to a grease consistency with 5-30% by weight, based on total composition, of alkali metal soap of α C_{12}—C_{22} substantially saturated fatty acid, said lubricating oil comprising about 10-60% by weight, based on total composition, of a lubricating oil base selected from the group consisting of lubricating grade di-esters of aliphatic monohydric alcohols with aliphatic dibasic acids having 4-12 carbon atoms and lubricating grade light mineral oil, and about 20-60% by weight, based on total composition, of a lubricating oil grade complex ester formed of 1.0 mol of butyl alcohol, 0.5 mol of triethylene glycol, and 1 mol adipic acid.

Viscosity Index Improvers, Patent No. 2,782,167 (T. S. Tutwiler, assignor to Esso Research & Engineering Co.) A lubricating composition comprising a lubricating oil having combined therein from 0.01% to 10.0% by weight of an oil soluble copolymer of from 20% to 50% by weight of a methoxy vinyl ether having the general formula $CH_3—(O—CH_2—CH_2)_n—O—CH=CH_2$ wherein n is an integer from 1 to 2 with from 80% to 50% by weight of an alkyl vinyl ether having the formula $R—O—CH=CH_2$ wherein R is an alkyl group containing from 6 to 10 base to form a moist mixture, and then heating said moist within a range of from 8,000 to 30,000 Staudinger.

Rust Preventive Composition, Patent No. 2,783,156 (J. D. Oathout and R. W. Scott, assignors to Esso Research & Engineering Co.) A rust inhibiting composition of the solvent and film-forming type which consists essentially of about 73-80 wt. percent of a volatile hydrocarbon solvent boiling within the range of about 250-450 F., about 13-18 wt. percent of a non-volatile light hydrocarbon oil boiling within the range of about 500-600 F., about 2-3 wt. percent of white crude scale wax melting within the range of about 121-127 F., about 4-6 wt. percent of sorbitan mono-oleate and about 1-3 wt. percent of phenyl ethanol amine.

Water Displacing Corrosion Inhibiting Compositions and Process of Treating Metal Surfaces Therewith, Patent No. 2,784,104 (M. S. Baseman, K. S. Johnson and S. E. Baseman.) A homogeneous corrosion-inhibiting composition suitable for application to damp and wet metal surfaces, consisting essentially of a solution of from 75% to 99.8% by weight of a liquid oleaginous vehicle consisting essentially of a hydrocarbon lubricating oil of a viscosity of below 50 poises at 25 C., from 10% to 0.1% by weight of a hydrophilic wetting agent dissolved in the vehicle, the wetting agent being selected from the group consisting of petroleum sulfonates, sorbitan monolaurate, sorbitan monopalmitate, sorbitan monooleate and sorbitan monopalmitate polyoxyethylene derivatives, and from 15% to 0.1% by weight of the reaction product of substantially equimolar proportions of dicyclohexylamine and octanoic acid.

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DISCUSSION, By S. B. Twiss, Chrysler Corp.

This paper is well organized and a timely reminder of the usefulness of the electron diffraction technique in the study of surface films. The paper is particularly helpful to those who are unacquainted with electron diffraction methods or the contributions of this technique to lubrication research.

I believe the author should have pointed out that electron diffraction results may lead to inaccurate conclusions about lubricating films. For electron diffraction to be of use in identifying a film, it must be crystalline or at least contain oriented molecules. Unfortunately, diffuse halos, which are characteristic of surfaces having amorphous organic or inorganic films or microcrystalline phases, are very common in lubrication research. If such an amorphous film is present, together with a well-defined crystalline layer, e.g. iron oxide, the researcher might come to the conclusion that the iron oxide film is the only one present or the most important one from the viewpoint of lubrication. It is probably the exception rather than the rule that films present on wear of surfaces are crystalline films. It is more probable that wear surfaces consist of complex, multi-layered films which contain amorphous or microcrystalline phases. Thus, although capable of giving information on simple crystalline phases, electron diffraction may give misleading impressions about the complex lubricant films which are most important in decreasing the wear or friction of contacting surfaces.

I should also like to question the implication by the author that electron diffraction is the most useful technique in revealing information on the nature of a surface. This may be true as regards the chemical composition of the surface, but is certainly not true from the viewpoint of the physical or geometric characteristics of a surface, which are better revealed by microscopic methods. In fact, it is highly desirable to combine electron diffraction examination with other techniques which have shown their value in lubrication studies such as:

- Light microscopy, which is primarily useful for showing the degree of surface damage due to scuffing and wear.
- Electron microscopy, which is useful for observing very minute changes in the surface, and the size and shape of wear particles, which are not observable by light microscopy.
- Profilometer and Proficorder techniques which are useful for determining surface roughness and the profile of wear scars.
- Chemical and electrographic analyses, which are useful for establishing the chemical elements present in surface films.
- Radiographic techniques, which are useful for determining the adsorption of lubricant additives, or the degree of wear and metal transfer of contacting surfaces.

Only by using a combination of these techniques, together with electron diffraction, is it possible to get a more complete picture of the mechanism of lubricant function.

AUTHOR'S CLOSURE

The author agrees wholeheartedly with Dr. Twiss' thought that the use of a combination of techniques is necessary to give the complete story of the lubricated surface. In fact, the author uses the techniques mentioned by Dr. Twiss and in addition, X-ray fluorescence and emission spectroscopy. However, electron diffraction should be recognized as being particularly suited to lubrication studies because of its sensitivity to those superficial zones where sliding occurs. In addition, the ability to detect the existence of an amorphous state and the existence of preferred orientation is unique. The author would like to take this opportunity to mention that a number of laboratories are developing a method of electron diffraction with low energy (less than 1000 volts) electrons. This development will further increase the sensitivity of electron diffraction to surface material.

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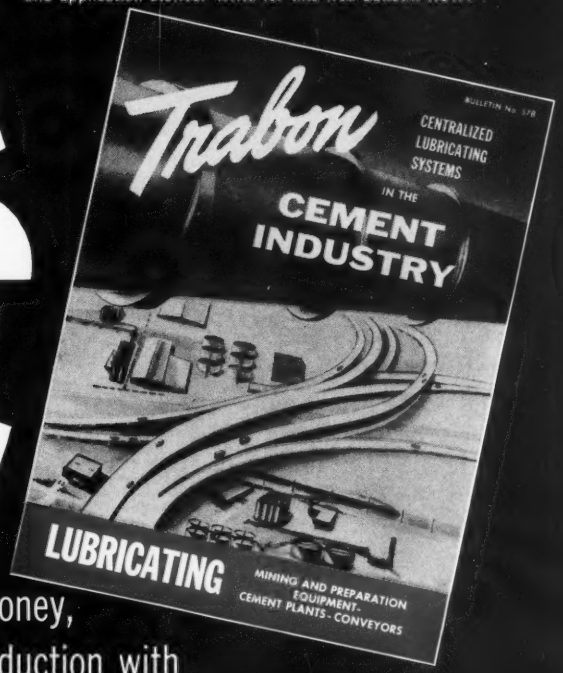

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